Propeller Programming

Using Assembler, Spin, and C

—

Sridhar Anandakrishnan

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About the Author

Sridhar Anandakrishnan is a professor of glaciology and geophysics at Pennsylvania State University where he studies the flow of glaciers in Antarctica and Greenland. Sridhar uses the Propeller chip in a seismic data acquisition device that is used "on the ice," as they say!

Acknowledgments

I would like to thank Peter Burkett, Bruce Long, and Don Voigt for their help in the lab and in the field. They designed and deployed rugged and precise instruments in Antarctica and Greenland that helped to shape our knowledge of those continents. I would like to thank the US National Science Foundation, whose financial and logistical support has made this work possible. I would like to thank my wife Martha Bright, whose love and support has made this book possible.

Preface

This book is intended for those who are familiar with Spin programming for the Parallax Propeller microcontroller but who want to learn Propeller C and Propeller Assembly (PASM) programming. The overall task you will pursue in the book is to implement a delta compression algorithm (a way to store a string of numbers in less space), first in Spin, then in PASM, and finally in C. Along the way, I talk about Test-Driven Development and will end with a chapter on hardware manipulations.

Intended Audience

It will be helpful to have some knowledge of a programming language. The intent is to help you extend the capabilities of the Propeller processor by using C and the Assembler language. If you don't know Spin but do know another programming language (C or Python, for example), you will still be able to follow along actively.

You will learn by doing, so you must purchase a Propeller board such as the QuickStart board (`https://www.parallax.com/product/40000`) so that you can run the code.

Formatting

In this book, code listings are typeset in a typewriter font: `nSamps := 1`.

To keep the bloat down, I often elide lines that have been explained earlier. I will insert an ellipsis to indicate that: `....`

Lines of code in Spin may not have a line break. When a long line listing is broken into two because of the page width, this is indicated with an arrow: (↩). You can download the code examples from GitHub (`https://github.com/Apress/propeller-programming`). Two libraries (`FullDuplexSerial4PortPlus_0v3` and `Numbers`) are used in the code. Both can be downloaded from the Propeller Object Exchange (`http://obex.parallax.com`), and for convenience I include them in the GitHub repository.

Trains

As you will discover, I like trains! But my choice of trains as an analog for the Propeller isn't entirely arbitrary. Like the Propeller, train stations have many parallel tracks with trains moving at different speeds and performing different tasks and with the need to somehow communicate between each other and with the outside world.

As with trains there is always the possibility of a crash! Gentle programmer, as in any journey, you will experience tears and heartache en route to your destination, but if you persist, there is a great reward at the end of the journey!

PART I

Introduction

CHAPTER 1

Introduction

This is a tutorial on programming the Propeller microcontroller using both the C programming language and the Propeller Assembly (PASM) language. For many years after its introduction, the Propeller could be programmed in Spin and PASM; more recently, Parallax (the company behind the Propeller) has made a C compiler available. Spin and C are high-level *interpreted* and *compiled* languages, respectively. PASM is a *low-level* language, with a one-to-one correspondence between an instruction and the Propeller's machine code.

The advantage of PASM over Spin (and to some extent C) is speed. PASM is faster than Spin by almost two orders of magnitude, and it is faster than C by a factor of about two to five. The disadvantage of PASM is that it is cryptic and has fewer helpful shortcuts. A common task such as a loop is a single statement in C or Spin but requires more effort in PASM. Furthermore, Spin and C are well-documented, and there are a number of books and tutorials available. To learn PASM, you can turn to far fewer resources. This book is an attempt to fill that gap.

Together, we will first program a *compression/decompression* algorithm in Spin and then in PASM and finally in C and PASM. Compression refers to the process of taking a set of numbers and processing them in such a way that they can be stored in less space than they would have originally taken up. In lossless compression, those compressed numbers must still retain all the information in the original set of numbers (in lossy compression, we accept some degradation of the information in the numbers). The process of decompression is one in which those original numbers are generated from the compressed ones. In this book I will implement a lossless compression algorithm popular in the earthquake research community known as *delta compression* or Steim compression (named after its originator). Steim compression can reduce the space needed to store a *seismogram* (the sequence of numbers from an instrument for measuring ground motion due to an earthquake) by a factor of two or three.

We will work through the code for compression and decompression in Spin and in C. I then reproduce that code in PASM. The intent is that you should be able to follow the Spin/C code if you know some programming language. Thus, when you plunge into the PASM programming, you can focus on translating what you know from the higher-level language to the lower-level one.

If the speed of compression/decompression for the Spin/C code is fast enough to handle the sampling data rates, there may be no need to use the PASM code. For higher sampling rates, we will need to use a PASM program. Nevertheless, the Spin/C code is useful to write and run as a way to generate input for testing the PASM code.

The Propeller is most often used as an *embedded* controller to read and write electrical signals on its input and output pins. I will demonstrate these hardware interactions in all three languages as well. In this book I start with all the interaction through the terminal. Later, so that we can debug PASM code, it can be helpful to toggle a pin to see when the code enters and exits particular parts of the program. For that a logic analyzer or an oscilloscope is needed.

In the end, I find that the most convenient combination that balances simplicity of programming language and speed of operation is to use C with particular sections written in PASM.

Disclaimer I use and enjoy programming the Propeller, but I'm by no means an expert. If you find mistakes or have suggestions for new content, I welcome corrections and improvements.

Chapters 1–4 are an introduction to the device, to the Spin language, and to Test-Driven Development. Chapters 5–10 cover the PASM programming language and hardware interactions. Chapters 11–14 cover the C language and the various modes of programming the propeller in C: pure C, so-called Cog C, and mixed C and PASM programming. I end with a chapter on using an inline assembler that injects assembly code to speed up sections of C code.

1.1 The Propeller Eight-Cog Processor

The Propeller microcontroller is a versatile and powerful device. What sets it apart from most other microcontrollers is that there are in fact eight independent, parallel, but cooperating microcontrollers (known as *cogs*) within each Propeller microcontroller. You use as many or as few cogs as you need to do the job (and can turn cogs on and off, as needed, to conserve power).

There is a wealth of information about the Propeller on the Parallax web site[1] and even more on the forums.[2]

- You will need a Propeller board (available from Parallax for $25 to $80).
- You *must* download or purchase the Propeller manual.[3]

[1]`https://parallax.com`
[2]`https://goo.gl/enX7pB`
[3]`https://www.parallax.com/downloads/propeller-manual`

- Also take a look at the Q&A.[4]
- There are detailed tutorials and getting-started guides at the web site at `http://learn.parallax.com`.

An Opinionated Aside The Propeller is of remarkable (unique?) design because of the eight parallel *cogs*, or processors. Embedded systems (programmable controllers that are often "hidden" from users but interact with the physical world through electrical signals) require careful attention to detail when it's possible for more than one signal to arrive at nearly the same time. That worry about timing doesn't go away with the Propeller, but it is much alleviated by having eight *truly* parallel processors that can monitor and respond to events independently of each other.

The other remarkable aspect of the device is that it is useful (and used) by folks in the hobby/maker/education community as well as in commercial products.

Finally, the Propeller community is fantastically helpful. Ask questions (any question, no matter how basic) on the forums, and beginners will get a friendly welcome and gentle nudge in the right direction; those with more advanced questions sometimes get a complete, tested solution!

1.1.1 Cogs

A *cog* is a microprocessor (one of eight within the Propeller that can be individually activated and deactivated by other cogs). You provide a cog with a set of instructions and an order in which to execute those

[4]`https://www.parallax.com/propeller/qna/`

instructions. The cogs run in *parallel*, meaning that all the active cogs respond to each clock cycle in parallel (more on this later). A program always starts on one cog known as the *main cog*. The main cog can selectively start and stop up to seven other cogs that can independently perform tasks. All the cogs have access to all the input and output lines of the Propeller.

The Propeller as a whole can run at a variety of clock speeds depending on the needs of the program and the desire for reducing power consumption (slower speeds and fewer cogs consume less power, unsurprisingly).

Each of the eight cogs of the Propeller can operate at approximately 20 million instructions per second (MIPS) . And because the cogs run on *separate pieces of hardware*, the total capacity of the Propeller is something closer to 160MIPS.

- Each cog has access to all 32 input/output pins of the Propeller. Each cog has access to an internal counter that increments once per clock cycle and to two programmable counters that can be associated with pins.
- Each cog has access to a 32 kilobytes (KB) shared memory area called the *hub*.
- The propeller runs a Spin interpreter that converts Spin code (stored in the hub) to PASM instructions that are then copied to a cog and run there.
- Alternatively, each cog can be programmed directly in PASM; a PASM program consists of a few hundred *instructions*.
- Each cog has 2KB of internal memory for storing instructions and data.

PASM instructions fall into a few families.

- Assignment, addition, and subtraction.
- Bitwise logical operations (AND, OR, and so on).
- Bit manipulations (shift or rotate `longs` by a certain number of bits).
- Hub memory access (reading and writing to the hub).
- Waiting for a condition to be met (e.g., waiting for the counter to equal a value, waiting for a pin to equal a state).
- Changing the location where execution will continue (jumping to an address); without an explicit jump, the next instruction in memory is executed.
- Setting or clearing a shared lock in an atomic fashion.
- Starting and stopping cogs.
- Conditional execution of an instruction based on the value of two special flags, `Z` and `C`.
- Setting the `Z` and `C` flags. Many of the instructions mentioned can and do change these flags precisely for use by the conditional execution step.

In Figure 1-1, you can see the effect of clock speed on current consumption. The Propeller can dynamically change clock speed, so you could, for example, run at a slow speed (low power) while waiting for an event and then switch to a higher speed to process data.

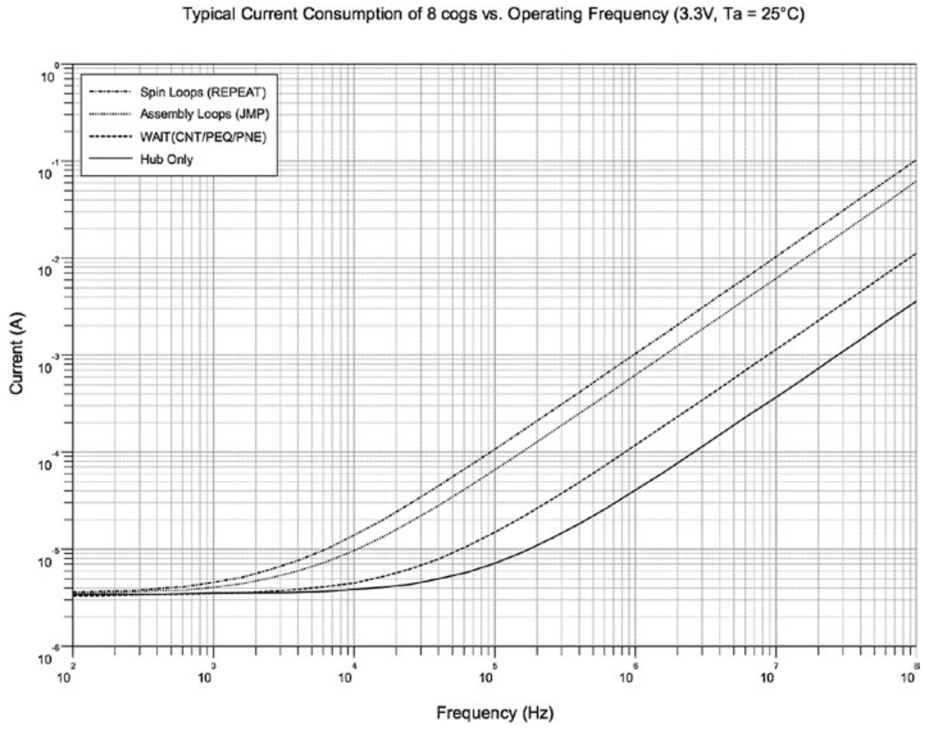


Figure 1-1. *Current consumption for eight cogs under different conditions. Horizontal axis is frequency from 100Hz to 100MHz, and vertical axis is current from 1μA to 1A. Source: Propeller P8X32A Datasheet, Parallax Semiconductor, 2011.*

1.1.2 Hubs and Cogs

The *hub* serves as a common area with 32KB of storage (versus 2KB in each cog). Each cog keeps immediately needed instructions and data internally but can request other data and instructions from the hub as needed. The key difference between cog memory and hub memory is latency. Cog memory is available instantly; hub memory operates on a round-robin basis. Each of the eight cogs is given a window of access to the hub, and if a cog misses that window, it must wait until the hub "rotates back" to it (Figure 1-2).

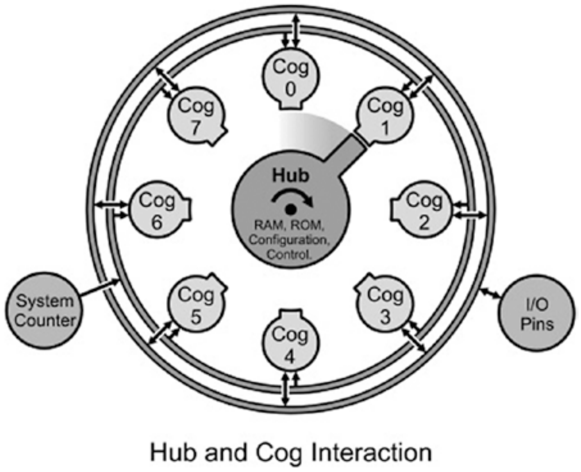


Figure 1-2. *The relationship between the hub and cogs. The hub rotates to the next cog every four clock cycles, and at that time, the cog can exchange data with the hub. Source: Propeller P8X32A Datasheet, Parallax Semiconductor, 2011.*

Initially only one cog is running. You can start up a second cog, which will run at the same clock speed and in parallel to the first cog. In other words, both cogs will execute their own instructions at *exactly the same time*. This is particularly valuable in cases where timing is critical or in cases where you need to read data from a pin at high speed (or, more likely, if you need to do both things at once).

For example, let's say we want to monitor the pulse-per-second (PPS) line from a GPS receiver[5] to synchronize the internal clock to an absolute time standard. At the same time, we may be reading data from a digitizer at rates of 100 kilobits per second (Kbps). This is 100,000 bits per second or approximately every 10μs. One way to structure this program would be to have two cogs running in parallel where the first does nothing but wait for the PPS line to rise and to set the clock when it does; the second cog could be independently reading the data line.

[5]GPS receivers are some of the most accurate clocks in existence. Even an inexpensive GPS receiver has time accuracy of a few tens of nanoseconds.

The only time that the cogs are not completely independent is when they want to access hub resources. For example, if a cog wants to write data to hub memory, it waits its turn. The hub operates in round-robin fashion and gives each of the eight cogs its window of opportunity to write to the hub (Figure 1-2 shows a railroad turntable that is analogous: the different locomotives can access the central hub only when it's their turn).

Multi-core vs. single-core processors To be fair, everything you will do with a Propeller microcontroller can be done with a single-processor machine. A single-processor machine—even a relatively simple one—can easily keep up with a 100Kbps data stream. These processors may have a counter module that could be set to be triggered by the PPS line, so you could synchronize to GPS time, or they may be capable of setting the PPS line as a hardware interrupt that will call a synchronization subroutine when the PPS signal arrives.

There are proponents of the Propeller, and there are those who like other processors. What I find appealing about the Propeller is the elegance of separating functionally different tasks into different cogs.

1.2 Memory Layout

We will be doing lots of messing about with memory locations and whether a number is a byte or a long, and so on, so this section is a quick high-level introduction to what the Propeller "looks like" on the inside. There are two areas of memory that we will be dealing with. One is *hub memory*. This is a 32KB area of shared space where program instructions and variables, as well as special-purpose registers, are saved. We will mainly be focusing on variables' storage and access to some of those special registers.

In the propeller, memory is addressed by byte, word (two bytes), or long (4 bytes). In hub memory, one can use all three of these memory types, but in a cog, only bytes and longs are allowed.

The other area of memory is *cog memory*. There are seven such areas available (the eighth, cog 0, is generally not programmed by us in PASM). PASM instructions are placed in that space, as well as storage for any variables used by that cog. It is important to keep in mind that this space is completely separate from the hub memory (and from the cog memory for other cogs). If you want to interact with the other cogs, you must do so by writing to and reading from hub memory. We will spend some time looking at that. Figure 1-3 shows a railroad turntable. The engines are stored on the spokes of the turntable and the central hub rotates to access them as needed, in similar fashion to the Propeller.

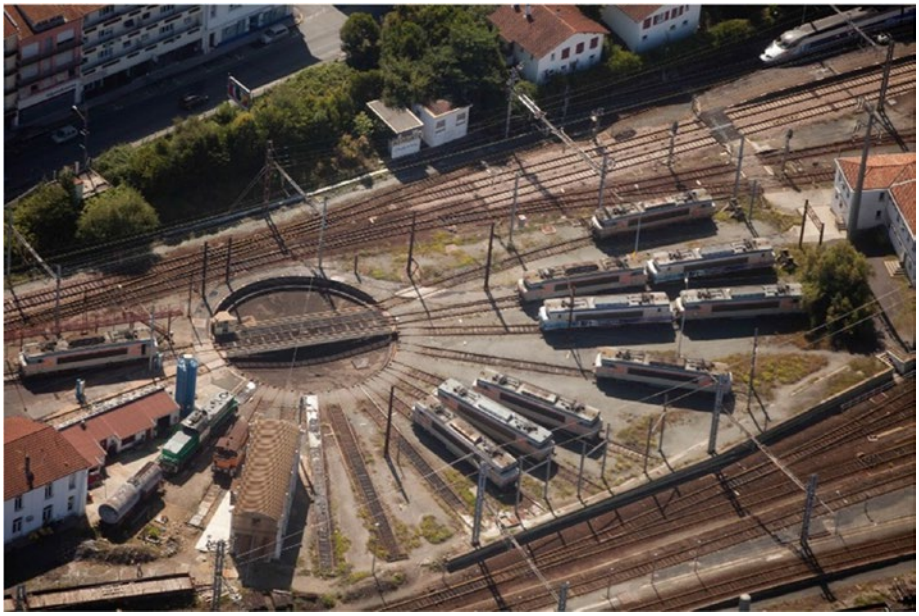


Figure 1-3. *A railroad turntable. To store locomotives in a yard and to access them at any time, the central turntable would rotate to a particular set of tracks; the locomotive would drive onto the turntable, and then the turntable would rotate to another set of tracks (or would rotate 180 degrees to reverse the direction of locomotive). Source: Photograph by Jeroen Komen. `https://goo.gl/PjJhgZ`. Distributed under the Creative Commons License CC-BY-SA 2.0.*

1.2.1 Hub Memory

All memory is addressed by byte. Listing 1-1 shows how memory is declared (reserved), and Figure 1-4 shows how the bytes are organized. The upper part of the code (before the DAT) is Spin code, which reserves space in hub memory; the part after the DAT is PASM code, which affects memory in a cog after a cognew command. (In this and subsequent code listings, an ellipsis [...] stands in for other lines of code that I'm not showing.)

Listing 1-1. Variable Declarations in Spin

```
...
VAR
  byte packBuf [8]
  long nSamps, sampsBuf [2]

PUB MAIN
  packBuf[0] := $00 ' not really necessary
  packBuf[1] := $00
  packBuf[2] := $00
  packBuf[3] := $00
  nSamps := $02
  sampsBuf[0] := $00_14_00_72
  sampsBuf[1] := $00_00_01_5c
  cognew(@PROG, 0)
...

DAT
PROG ORG 0
...
```

```
:loop
...
_ns res 1
_nsPtr res 1
FIT 496
```

All memory is addressed by byte (in both hub and cog memory).

The variables declared as byte values (`packBuf[i]`) are stored in consecutive memory locations.

However, the variables declared as long values (`nsamps, sampsBuf[i]`) are stored at every fourth memory location (because they take up four bytes each): `0x54`, `0x58`, and `0x5C`.

The order of memory storage follows the order of how the variables are declared in the `VAR` section. In other words, because I declared `nSamps` first and then `sampsBuf` immediately after, that is how the memory will look.[6]

1.2.2 Cog Memory

The cog memory is also addressed by byte, but unlike in hub memory, there is no provision to reserve byte-wide memory. Everything is stored in full longs. If you want to address a byte, you have to first address a long and then mask the eight bits corresponding to the byte of interest. Each cog has 512 longs of space (2KB), of which 496 are available to the user. The last 16 longs of cog memory are reserved for special registers (`PAR`, `OUTA`, etc.).

You put PASM instructions at address zero, and the Propeller will execute that instruction and then step to the next instruction at the next location (1 long higher), and so on. An instruction is simply a 32-bit number (a very special number where every bit is important and tells

[6]Don't interleave byte and long declarations in VAR. The Spin compiler will store all longs first, then all words, and then all byte variables, even if you declare a byte variable before a long.

the Propeller to do something particular—add these numbers, copy this number there, etc.—but just a number nevertheless), which means that if execution accidentally wandered into areas where you have variables stored, the cog will try to execute those as if they were instructions.

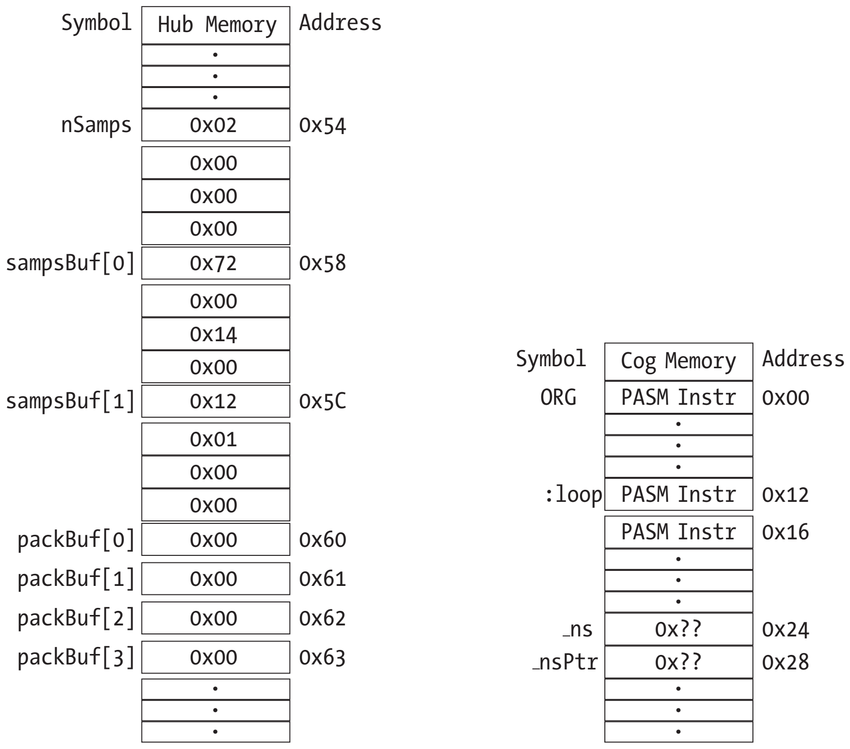


Figure 1-4. *Hub and cog memory layout from Listing 1-1. Note that memory addresses increase downward.*

1.3 Layout of This Book

In Chapter 2 I describe the underlying process of delta compression (or Steim compression). In Chapter 3 I introduce the Spin language and provide templates for a Spin program and a PASM "Hello, World" program. Here you can verify that your hardware setup is working (you *did* buy a Propeller board to run your code on, right?). In Chapter 4, I introduce a simplified version of Test-Driven Development (TDD), which I use in this book. In Chapter 5, I implement the Steim compression and decompression algorithm in Spin and verify that it is working using TDD.

Chapter 6 introduces PASM, and we begin the development of Steim compression code in PASM. In Chapter 7, I introduce methods for reading and setting pins. I implement a Serial Peripheral Interface (SPI) bus in Spin and in PASM and use that bus between two cogs (one running the main Spin code and one running the Steim PASM code). Next, I introduce semaphores (or locks) and end with examples of some useful routines in Spin: multiplication, division, loops, branching.

In Chapters 8 and 9 I continue the PASM compression algorithm development using TDD. In Chapter 10, I implement the Steim decompression routines in PASM, including TDD. Chapter 11 is devoted to some simple debugging methods for PASM code.

The last section of the book is devoted to using C to perform many of the same tasks. Chapter 12 introduces C and, in particular, the Propeller-specific peculiarities we will encounter; here we program the Steim compression routine in C. In Chapter 13 I describe *Cog-C* mode where the compression C code is launched in a new cog. In Chapter 14, I do the same but with a mix of C and PASM.

Finally, in Chapters 15 and 16, I go over the methods for interacting with hardware again, but this time in C.

CHAPTER 2

Steim Compression

Consider a freight train carrying goods—some big and some small—across the country. Rather than put each item in its own railroad car, the little things are combined and put in one car and then separated at the far end. Compression does much the same thing. Given a set of numbers (some small and some large), you squeeze the small ones together for storage and then take them apart when you need to use them.

This book is built around implementing a *delta compression* routine. Given a set of N numbers, S_i, $i = 0, \ldots, N - 1$, the Steim compression method is to form a set of backward differences: $\delta_j = S_j - S_{j-1}$, $j = 1, \ldots, N - 1$.[1]

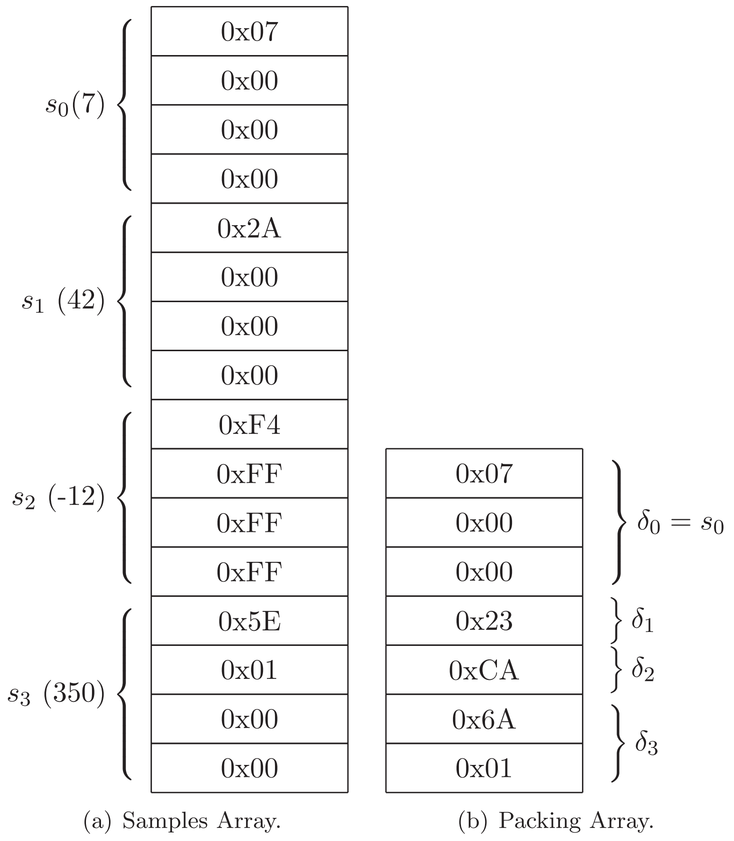
These differences (along with S_0, the first sample) are packed into a compressed string, where each difference may take up less space than the original sample. To uncompress the data, each difference must have an associated code c_i indicating how many bytes were used for storing the difference: c_i, $i = 0, \ldots, N - 1$.

[1]This technique was popularized by Dr. JM Steim and has been implemented by the International Federation of Digital Seismograph Networks. The best description is in the SEED Reference Manual, "Standards for the Exchange of Earthquake Data," `https://www.fdsn.org/seed_manual/SEEDManual_V2.4.pdf`. There is no published reference to Dr. Steim's work.

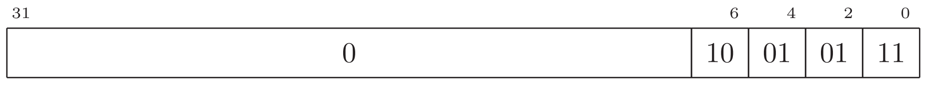
In this compression routine, the allowed sizes are 32 bits (4 bytes, or a `long` in Spin), 24 bits (3 bytes), 16 bits (2 bytes, or a word), and 8 bits (a byte). In more advanced compressors, 4-bit and 12-bit word lengths are allowed. I will leave that as an exercise for you!

2.1 Packing and Compressing Data

You can picture the memory impact of the compression with an example of four samples (7, 42, -12, 350) that must be compressed. Figure 2-1 shows the memory layout for these samples in panel (a) (from here out I will generally represent numbers in hexadecimal format and indicate that by prepending the number with `0x`). In panel (b) I show the compressed and packed buffer layout with the 3-byte sample 0 storage and the subsequent differences stored. In panel (c) I show the compression coding.



(a) Samples Array. (b) Packing Array.



(c) Compression coding

Figure 2-1. *Compression: (a) Samples are 4 bytes long but are packed into 1–3 bytes of differences of samples. (I know a priori that my numbers always fit in 3 bytes). (b) Sample 0 is stored as is; the difference between samples 1 and 0 is stored in the smallest number of bytes possible, and so on. (c) The length of storage is itself saved in the compression code array.*

It should be apparent that this compression method is best suited for time-series data where the mean of the numbers may be large but the standard deviation is small. Steim compression is most commonly used in data from seismographs (instruments that measure the ground motion to detect earthquakes). For much of the time, the seismographs are recording background noise, which has a small sample-to-sample variability. When an earthquake occurs, however, the seismograph output can and does change dramatically from one sample to the next. Figure 2-2 shows an example of a set of seismograms after a massive and destructive earthquake in Japan. All these data needs to be recorded and stored without any loss.

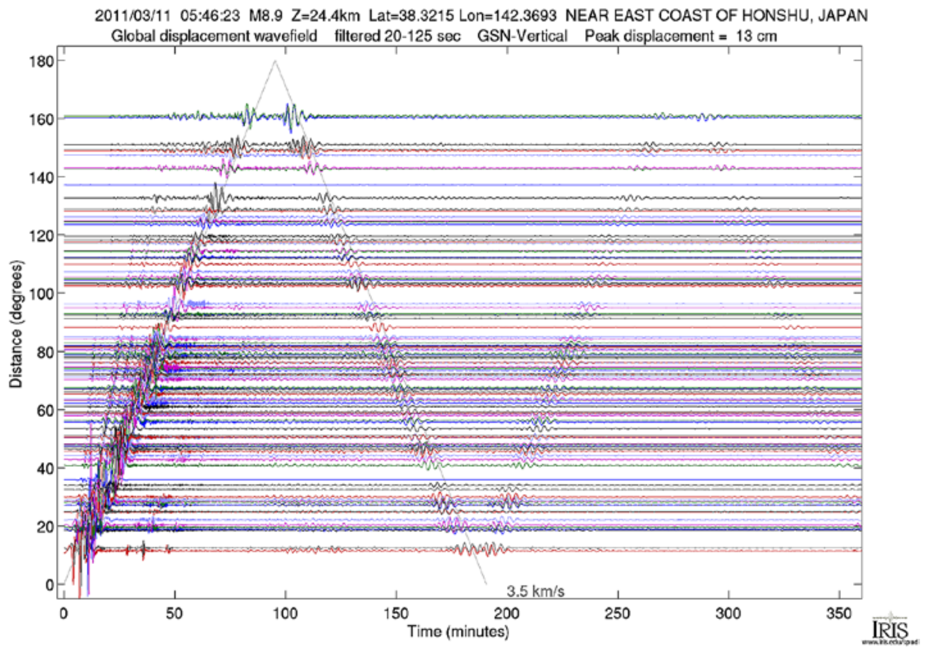


Figure 2-2. *Seismograms from around the world after the devastating Tohoku earthquake of March 2011 (magnitude 9). The lines show ground displacement at various seismographs ranging in distance from close to Japan (angular distance of 0 degrees) to the other side of the world from Japan (angular distance of 180 degrees). The horizontal axis is time after the earthquake occurs (in minutes). You can see the surface wave train travel around the world, back to Japan, and then repeat! In fact, the earth "rung like a bell" for hours after this event. Source:* `http://ds.iris.edu/ds/nodes/dmc/specialevents/2011/03/11/tohoku-japan-earthquake/`.

2.2 Specification

Input numbers must be valid 32-bit numbers, but the *dynamic range* of the samples is limited to 24 bits (that is the limit of our digitizer). Therefore, every sample can be represented and stored in at most 3 bytes. However, most programming languages prefer 4-byte numbers. Thus, on decompression, numbers should be 4 bytes long, with the uppermost byte *sign extended* from bit 23 (more on this later).

In the main cog, I will define the following:

- `nsamps`: A `long` variable holding the number of samples *N* to process.
- `sampsBuf`: A `long` array holding the samples s_i.
- `packBuf`: A `byte` array holding the compressed and packed differences δ_i.
- `codeBuf`: A `long` array holding the compression code for each compressed sample.
- `nCompr`: A `long` variable holding the populated number of bytes in `packBuf`.

Here is what happens:

1. The compression program will compress `nsamps` numbers from the `sampsBuf` array and populate the output variables `packBuf`, `codeBuf`, and `nCompr`.
2. If `nsamps` is greater than the length of `sampsBuf`, return an error by setting `ncompr` to `-1`.
3. For sample zero:
    - `STEIM` SHALL compress the first sample, s_0, by storing its bits 0 to 23 (the lower 3 bytes) into `packBuf`.
    - `STEIM` SHALL store CODE24 in the lowest 2 bits of `codeBuf`.
    - `STEIM` SHALL set `nCompr` to 3.

    (My digitizer has a 24-bit dynamic range, so all numbers fit within 3 or fewer bytes.)

4. For sample $j\ (0 < j < N)$:
    - `STEIM` will form the backward difference $\delta_j = s_j - s_{j-1}$ and determine whether the difference would fit completely within 1, 2, or 3 bytes and SHALL append those bytes to `packBuf`.
    - `STEIM` SHALL increment `nCompr` by 1, 2, 3, according as the number of bytes needed for δ_j.
    - `STEIM` SHALL place the appropriate code (`CODE08`, `CODE16`, or `CODE24`) in `comprBuf`.
5. Finally, the decompression routine takes as input `nsamps`, `packBuf`, `codeBuf`, and `nCompr` and SHALL populate `sampsBuf` correctly.

2.3 Implementation

Now that we have a concise specification for the procedure, we will implement it in the following chapters (first in Spin, then in PASM, then in C, and finally in C and PASM). The way we will build up the implementations is similar in all cases. We will write a test for each of the previous bullets, and then we will write the code so that it passes the test.

CHAPTER 3

Introduction to Spin

Let's set up a Spin and PASM template and make sure you can compile the Spin and PASM program, that you can connect to the Propeller and download the binary file, and that you can see the output.

A few notes: Spin is sensitive to indentation (PASM is not). Comments begin with a single quote (`'`) and continue for the remainder of the line. Block comments are delineated by curly braces (`{` and `}`).

In general, strive for simplicity and clarity in the code when starting out (even at the expense of speed). Once the code is working, you can tweak portions to speed them up if you need better performance.

Neither Spin nor PASM is sensitive to case. Nevertheless, we will hold to these conventions:

- All caps are used for block identifiers (`CON`, `OBJ`, `VAR`, `PUB`, `PRI`, and `DAT`), constants, and function names (also called method names).
- Words in function names are separated by underscores (_).
- Variable names use lowercase and "camel case" (capitalized second and later words, for example, `sampsPerSecond`).
- An underscore is used as the first letter of variables in PASM code.
- A lowercase *p* is used as the first letter of array address variable names ("pointers") in functions.

S. Anandakrishnan, *Propeller Programming*, https://doi.org/10.1007/978-1-4842-3354-2_3

Finally, Spin has a flexible and friendly way of representing numbers. Prepend $ (dollar sign) for hexadecimal numbers and % (percent sign) for binary; numbers without a preceding symbol are decimal numbers. You can insert underscores anywhere in a number, and they are ignored by the compiler. They are syntactic "sugar" to help reduce errors—particularly with binary numbers with long strings of ones and zeros. So, you can say this:

```
pi4 := 3 _1415 ' the _ is ignored pi4 =31415
pi4 := $7A_B7
pi4 := %0111 _1010_1011_0111
```

BINARY AND DECIMAL AND HEX, OH MY

The Propeller (and computers in general) store numbers in *binary* format.

- In a *decimal* representation of a number (what we are used to in real life), digits can range from 0 to 9, and a number like 42 is read as "2 times 1 plus 4 times 10."
- In a *binary* representation, only the digits 0 and 1 are allowed, and the number 42 is represented as 101010, which is read as (right to left) "0 times 1 plus 1 times 2 plus 0 times 4 plus 1 times 8 plus 0 times 16 plus 1 times 32" (32 + 8 + 2 = 42).
- In a *hexadecimal* (or hex) representation, digits range from 0 to 9 and A to F (where *A* is 10, *B* is 11, up to *F*, which is 15). The number 42 is represented as 2A, which is read as "A, which is 10, times 1 plus 2 times 16" (32 + 10 = 42).

In this book (and many computer books), a hex number is written as 0x2A (the 0x signals that the number should be interpreted as a hex number). However, in a Spin or PASM program, that would be written as $2A. In a C program, that would be written as 0x2A.

In this book and in C, a binary number is written as 0b00101010. In Spin and PASM, it is written as %0010_1010.

Yes, I know, it would be nice if we could all agree to use the same vocabulary, but what a boring world that would be!

```
theAnswerDec := 42        ' decimal 42
theAnswerHex := $2A       ' hexadecimal 0x2A
theAnswerBin := %00101010 ' binary 0 b00101010.
```

By convention, we show only as many decimal numbers as needed, so for example for the number 7, we don't say 007, just 7. However, also by convention we always show hex numbers in groups of two, so we would write that as $07 or 0x07, and in binary we show groups of eight: %0000_0111 or 0b00000111.

There are 8 binary digits per byte and 2 bytes per word (16 bits) and 4 bytes per long (32 bits). A byte is a collection of 8 bits. A byte can contain *unsigned* numbers from 0 to 255; a word can contain numbers from 0 to 65,535; and a long can contain numbers from 0 to 4,294,967,295 (about 4 billion).

The advantage of a hex representation is that each *byte* (a collection of 8 bits) can be succinctly *and naturally* written as two hex digits. The largest number that can be written in 8 bits is the number you and I know in decimal as 255 (5 times 1 plus 5 times 10 plus 2 times 100) or binary *11111111* (I won't write out the sums here, but you should). In hex, that number is *FF* (15 times 1 plus 15 times 16). There are many advantages to this method of writing numbers and many resources on the Web for understanding it.

One enormously useful tool is a calculator app that has a "programmer's mode" that can show numbers in the different *bases* (bases are the underlying number system, either binary, decimal, or hex).

3.1 Negative Numbers

If we decide that an eight-bit number is *unsigned*, then it can store numbers from 0 to 255 (`%0000_0000` to `%1111_1111`: 1 times 1 plus 1 times 2 plus 1 times 4, etc., up to 1 times 128 = 255).

However, if we decide that an 8-bit number is *signed*, then it can store numbers from -128 to 127. The most significant bit is referred to as the *sign bit*, and if it is 1, then the number is a negative number. Thus, the same set of bits (e.g., *i* =`%1111_1111`) would be *i* = 255 if *i* were signed, and it would be *i* = –1 if *i* were unsigned.

Negative numbers are stored in a "two's-complement" representation.[1] You don't need to worry about the details of what that means, except to be careful when changing the size of storage from, for example, 8 bits to 32 bits. Now that we have "laid the rails" for our work (Figure 3-1 shows some actual rails!), let's look at how the propeller implements memory.

[1]See the Wikipedia page at `https://en.wikipedia.org/wiki/Two%27s_complement` for more information.

***Figure 3-1.** A crew of railroad workers poses for the camera in 1911. Photographer unknown. In Nelson, Scott Reynolds (2007), Ain't Nothing but a Man: My Quest to Find the Real John Henry, National Geographic Books, ISBN: 9781426300004.* `https://upload.wikimedia.org/wikipedia/commons/5/51/A_crew_of_railroad_workers_poses_for_the_camera_in_1911.jpg`*. Wikimedia Commons, no license attached.*

3.2 Memory Layout

Absolute memory addresses increase from zero, incrementing by one for each byte. There are three storage lengths in the propeller: bytes, words (2 bytes), and longs (4 bytes).

Propellers are *little-endian* devices. Thus, the lowest byte of a long number is stored at a lower memory location than the higher bytes in that number. (Note that the Propeller happily allows you to modify *any* memory location!)

3.3 Spin Template

Let's start with the Spin file. Listing 3-1 is a template that you can use to make sure your Propeller is working and connected and that the compiler and loader on your computer are working. There are a couple of options for the computer side. Parallax supports an excellent Propeller Tool[2] (Windows only), and there is a cross-platform PropellerIDE tool[3] (both of which have a compiler, program loader, and serial terminal included). I use separate command-line tools for compiling the code (`openspin`) and loading the Propeller (`propeller-load`), which are included with the PropellerIDE package.

The Propeller Tool and the PropellerIDE tool both include an editor that colorizes the code and handles indentation properly. You can also use a stand-alone text editor (such as Atom, emacs, and vi) and use command-line tools.

3.3.1 Hello, World

Trust Me, It's Good for You! I know this seems silly, but instead of downloading this file from GitHub or cutting and pasting this from the screen, *type in the whole file by hand!* It may seem like a waste of time, but I guarantee you that in the process of finding bugs and fixing them, you will learn way more than you can imagine.

---

[2] https://www.parallax.com/downloads/propeller-tool-software-windows-spin-assembly

[3] https://www.parallax.com/downloads/propeller-p8x32a-software

Listing 3-1. Spin Program Template for "Hello, World"

```
{*
 * Spin Template - curly braces are block comments
 *}
' single quotes are line comments
CON ' Clock mode settings
  _CLKMODE = XTAL1 + PLL16X
  _XINFREQ = 5_000_000

  ' system freq as a constant
  FULL_SPEED  = (( _clkmode - xtal1) >> 6) * _xinfreq
  ' ticks in 1ms
  ONE_MS      = FULL_SPEED / 1_000
  ' ticks in 1us
  ONE_US      = FULL_SPEED / 1_000_000

CON ' Pin map

  DEBUG_TX_TO   = 30
  DEBUG_RX_FROM = 31

CON ' UART ports
  DEBUG              =      0
  DEBUG_BAUD         = 115200

  UART_SIZE          =    100
  CR                 =     13
  LF                 =     10
  SPACE              =     32
  TAB                =      9
  COLON            =     58
  COMMA            =     44

OBJ
  UARTS : " FullDuplexSerial4portPlus_0v3 " ' 1 COG for 3 ↩
  serial ports
  NUM : " Numbers " ' Object for writing numbers to debug

VAR
  byte mainCogId, serialCogId

PUB MAIN

  mainCogId := cogid
  LAUNCH_SERIAL_COG
  PAUSE_MS(500)

  UARTS.STR(DEBUG, string (CR, LF, " mainCogId : "))
  UARTS.DEC(DEBUG, mainCogId)
  UARTS.STR(DEBUG, string (CR, LF, "Hello, World !", ↩
  CR, LF))
  repeat
    PAUSE_MS(1000)

PUB LAUNCH_SERIAL_COG
" method that sets up the serial ports
  NUM.INIT
  UARTS.INIT
  ' Add DEBUG port
  UARTS.ADDPORT(DEBUG, DEBUG_RX_FROM, DEBUG_TX_TO, ↩
  -1, -1, 0, %000000, DEBUG_BAUD)
```

```
58     UARTS.START
59     serialCogId := UARTS.GETCOGID
60     ' Start the ports
61     PAUSE_MS(300)
62
63   PUB PAUSE_MS(mS)
64     waitcnt(clkfreq /1000 * mS + cnt)
65
66   ' Program ends here
```

- **Lines 1–4**: Comments.
- **Lines 5–31**: Constants (CON) blocks. They are separated into individual blocks solely for purposes of organization.
- **Lines 33–37**: Objects (OBJ) block. The compiler will read the files named in quotes to the right of the colon (after appending .spin to the name) and assign constants and methods to the symbol to the left of the colon. So, all functions in Numbers.spin are available as NUM.FUNCTION_NAME. A function is a block of code that can be called, possibly with arguments (you will sometimes see them referred to as *methods*).
- **Lines 39–40**: Variables declaration block VAR. Variables declared here are initialized to zero. The size of memory is determined by the variable type (byte, word, or long).
- **Lines 42–50**: The first function in the top-level (or entry) file is executed by the Spin compiler in cog 0. By convention, we call it MAIN.
- **Lines 52–65**: Functions that can be called by MAIN.

The first CON block is the declaration of a set of constants for the Propeller clock. For now, simply copy the lines. I'll come back to what they mean later. The second and third blocks are constants for the serial port. In constant blocks, the constant name and value are separated by an equal sign (=). Later in the code, assignment to variables is done using :=.

The next block (OBJ) is like #include in C; it's a way to bring in external libraries. The desired name for the library and the string containing the file name of the library (without the .spin extension) are separated by a colon.

```
LIBNAME : "LibFile" ' read in file LibFile.spin and assign it
to LIBNAME
```

From now on you can refer to the functions and constants in that library by invoking this:

```
LIBNAME.LIBFUNCTION to call a function or method LIBFUNCTION in
library LIBNAME and LIBNAME#LIBCONSTANT to refer to a constant
LIBCONSTANT defined in that library[4].
```

The next block is a VAR where variables are declared and initialized to zero.

Finally, the actual program begins at the first PUB method (named MAIN by convention). This block is run automatically after the program is loaded on the Propeller. This is the "entry point" into the program (like int main() in C). From within MAIN you can call functions with any required arguments in parentheses. If there are no arguments, there is no need for the parentheses.

In the template some of the function calls are part of Spin (cogid, for example), some are written by us (PAUSE_MS), and some are part of an

[4]The two libraries are available on the Propeller Object Exchange (obex.parallax.com) or in the GitHub repo (https://github.com/sanandak/propbook-code).

object or library (UARTS.STR). Functions may return a value (for example, cogid does), which we can assign to a variable using := (a colon followed by the equal sign).

3.3.2 Running the Program

If you have openspin and propeller-load (or propman) on your path (Linux and macOS),[5] the following are the commands to run from a terminal.

The following will create a .binary file:

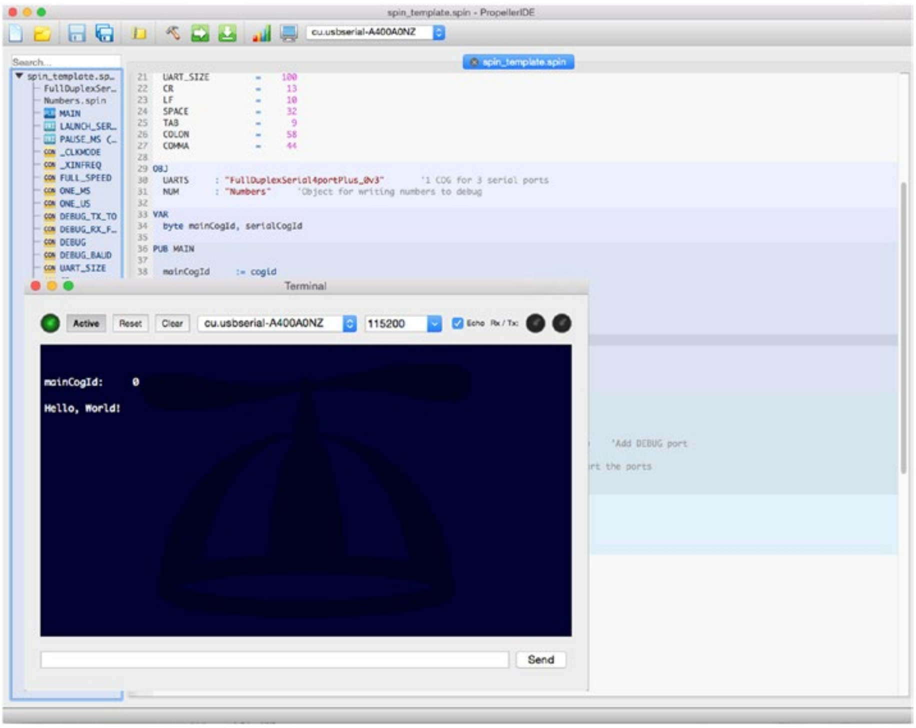
```
$ openspin ./spin_template.spin
```

The following command will send it to the Propeller. Your serial port number will differ. The propeller-load program is invoked with the -r and -t flags that instruct the Propeller to run the program after it is downloaded and to start a terminal to view messages from the Propeller, respectively.

```
$ propeller-load -p /dev/cu.usbserial-A103FFE0 \
                 -t -r spin_template.binary
Propeller Version 1 on /dev/cu.usbserial-A103FFE0
Loading spin_template.binary to hub memory
3924 bytes sent
Verifying RAM ... OK
[Entering terminal mode. Type ESC or Control-C to exit.]
mainCogId:     0
Hello, World!
```

[5]Using sh or bash on a Mac, the command is as follows: export PATH=/Applications/PropellerIDE.app/Contents/MacOS/:$PATH. On Linux, the command is as follows: export PATH=/opt/parallax/bin:$PATH.

Alternatively, you can use the PropellerIDE shown in Figure 3-2.[6]


```
  UART_SIZE            =    100
  CR                   =     13
  LF                   =     10
  SPACE                =     32
  TAB                  =      9
  COLON                =     58
  COMMA                =     44

OBJ
  UARTS     : "FullDuplexSerial4portPlus_0v3"      '1 COG for 3 serial ports
  NUM       : "Numbers"     'Object for writing numbers to debug

VAR
  byte mainCogId, serialCogId

PUB MAIN

  mainCogId      := cogid
```

```
mainCogId:    0
Hello, World!
```

Figure 3-2. Main window and terminal window for PropellerIDE

Congratulations! You have successfully seen that the Propeller is attached, that you can communicate with it, that the clock is set correctly, and that you can compile and download a program and view the output. That's a lot!

[6] https://www.parallax.com/downloads/propelleride-software-mac

3.4 PASM Template

Let's add a minimal PASM cog called `HELLO`. Here we will include the code for the new cog at the end of the `template.spin` file (copy the template to `hello0.spin`). Later, when we start working on the real code, we will put the Spin and PASM code in their own files. The main changes in the file are shown in Listing 3-2.

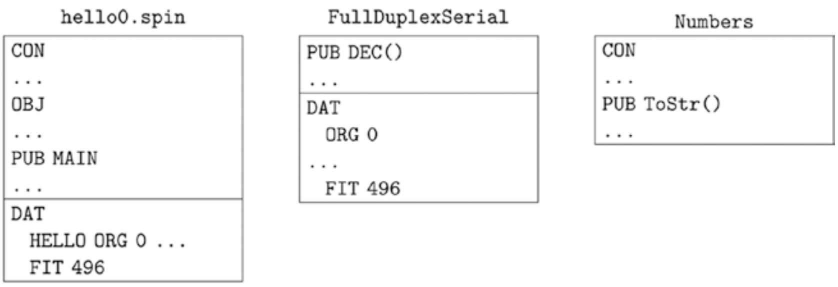
Listing 3-2. Changes to spin template.spin to Include PASM Cog Code (ch3/pasm template.spin)

```
...
' in VAR
  byte helloCogId

...
' in MAIN
  helloCogId := -1
  helloCogId := cognew(@HELLO, 0)

  UARTS.STR(DEBUG, string (CR, LF, " helloCogId : "))
  UARTS.DEC(DEBUG, helloCogId)
  UARTS.PUTC(DEBUG, CR)
  UARTS.PUTC(DEBUG, LF)
...

' in a new DAT section at end
DAT ' pasm cog HELLO
  HELLO ORG 0

:mainLoop
```

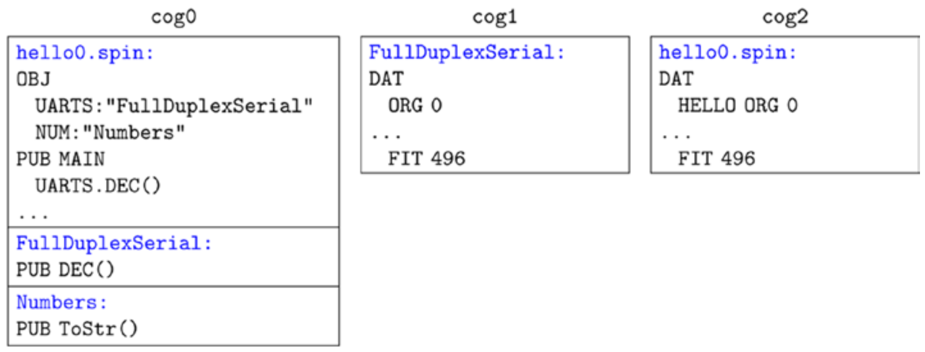
```
    jmp #:mainLoop

    FIT 496
```

This PASM code is the text between the DAT block marker and the FIT 496 instruction. This program does very little; it just runs an infinite loop (the jmp command jumps to the line labeled :mainLoop, which brings it right back to the jmp...).

The structure of the files and cogs is as follows. The file hello0.spin has the MAIN method, as well as a DAT section where the PASM program HELLO is defined. The file FullDuplexSerial has a Spin part where the methods DEC, HEX, PUTC, and so on, are defined, as well as a DAT part for the PASM code. Finally, the Numbers.spin file has only Spin code.



However the “cog view” of the Propeller is more like the following. The MAIN method calls a UARTS method (in the FullDuplexSerial file/object) named UARTS.START. This method includes a call to cognew that starts a new cog that manipulates the serial port lines with the correct timing. In addition, the MAIN method itself calls cognew. Each cognew command launches a new cog with code that is in the appropriate `DAT` section. At the end of the `MAIN` method, the cogs are as follows:



```
cog0
hello0.spin:
OBJ
  UARTS:"FullDuplexSerial"
  NUM:"Numbers"
PUB MAIN
  UARTS.DEC()
...
FullDuplexSerial:
PUB DEC()
Numbers:
PUB ToStr()
```

```
cog1
FullDuplexSerial:
DAT
  ORG 0
...
  FIT 496
```

```
cog2
hello0.spin:
DAT
  HELLO ORG 0
...
  FIT 496
```

So, for example, when `MAIN` calls the method `UARTS.DEC()`, that code runs in cog 0, but it passes instructions to cog 1 that does the actual hardware manipulations of the serial line.

Cog 0 isn't a special cog. When the Propeller boots, it loads a Spin *interpreter* into cog 0 that reads, interprets, and executes Spin code (code that is stored in hub memory). You can launch a second cog that also has a Spin interpreter, but in this tutorial, we will load PASM code into those new cogs.

Now run this (along with print statements to print out the serial and hello cog IDs):

```
%  propman  -t  hello0.binary
pm.loader:  [cu.usbserial-A400A0NZ]  Preparing  image...
pm.loader:  [cu.usbserial-A400A0NZ]  Downloading to RAM...
pm.loader:  [cu.usbserial-A400A0NZ]  Verifying  RAM...
pm.loader:  [cu.usbserial-A400A0NZ]  Success!
Entering terminal on cu.usbserial-A400A0NZ
```

```
Press Ctrl+C to exit
--------------------------------------
mainCogId:        0
Hello, World
serialCogId:      1
helloCogId:       2
```

(In this case I used the `propman` command instead of `propeller-load`.) Congratulations again! You have started a PASM cog successfully.

3.5 Template for PASM Code in a Separate File

Unless your PASM code is very simple, you will want to move that code to a separate file. This will allow you to turn that functionality into an *object* that can be included in any project.

Edit `hello0.spin` and create two files: `hello_Demo.spin` and `hello_pasm.spin`. The file `hello_Demo` is derived from `hello0` with the changes shown in Listing 3-3.

Listing 3-3. Changes to pasm template.spin When PASM Code Is in a Separate File (ch3/hello Demo.spin and ch3/hello pasm.spin)

```
...
OBJ
  ... ' add this
  HELLO: " hello_pasm " 'pasm cog is in a different file

PUB MAIN
...

  helloCogId := -1
```

```
   ' replace cognew (@HELLO, 0) with the following 2 lines
   HELLO.INIT
   helloCogId:= HELLO.START

   ' HELLO.STOP would stop the cog
...
' delete the DAT section
```

The line in the `OBJ` section will include the `hello_pasm` code as `HELLO`. Next, instead of calling `cognew` directly, you initialize and start the cog by calling functions in the library `HELLO`. The `HELLO.START` method will return the number of the newly launched cog.

Create a new file called `hello_pasm.spin` and type in the code in Listing 3-4.

Listing 3-4. Contents of hello_pasm.spin

```
{*
 * pasm template for code in a separate file from main
 *}

VAR
  byte ccogid

PUB INIT
  ccogid := -1

PUB START
  STOP
  ccogid:=cognew(@HELLO, 0)
  return ccogid

PUB STOP
```

```
17    if ccogid <> -1
18      cogstop(ccogid)
19      ccogid:= -1
20
21  DAT ' pasm cog HELLO
22  HELLO ORG 0
23
24  : mainLoop
25     jmp #:mainLoop
26
27  FIT 496
```

- **Lines 5–6:** Declare a variable `ccogid` that is local to this file. `ccogid` is either 0–7 for a valid cog number or -1 if the cog is not running.
- **Lines 8–9:** The `INIT` method, well, initializes variables. In this case, you want to ensure that `ccogid` is set to -1 to indicate that the cog is not running (when the variable is first declared, it is set to zero, which isn't what you want).
- **Lines 11–19:** The `START` and `STOP` methods are straightforward. Start a new cog (after stopping it, in case it is already running) and return the number of the newly launched cog. To stop a cog, make sure it really is running and then stop it. Set the cog ID to -1 to indicate that it is no longer active.

3.6 Summary

In this chapter, I laid some rails for running a new PASM cog. The cog does nothing so far. Again, I want to emphasize that once you launch a cog, it is *entirely separate* from other cogs. It has access to hub memory, but if two cogs want to share information through the hub, they both need some way to know where to look. The most confusing part of programming PASM for beginners is getting information into and out of the cogs (at least it was for me!).

Shall we try to connect the cogs? Figure 3-3 is a famous photograph of the ceremony when the two halves of the US Transcontinental railroad met and one could take a train from New York to San Francisco! Take a break and continue with the next chapter when you are ready.

Figure 3-3. *Connecting the Eastern and Western halves of the Transcontinental Railroad at Promontory Summit, Utah, May 10, 1869.*

CHAPTER 4

Test-Driven Development

One of the techniques I will be using is Test-Driven Development (TDD). You don't need to use TDD, but I find it helpful as a learning aide. TDD is rapidly becoming the norm in large software projects. The advantages of this method of development are manifold. In collaborative projects, developers can ensure that their changes don't inadvertently break something elsewhere. In long-lived projects, when you return to something from a long time ago, you can study the tests to maintain the code. Even in small projects (such as this one), using TDD will give you confidence that the results are correct.

The idea behind TDD is that you write a specification of what the program is supposed to do; you then write a test for a small piece of the program. Then, and only then, write the *minimal* amount of code that lets the test pass. Then write another test and another piece of code to pass that test…and run *all* the tests every time to make sure your changes haven't broken anything. Once you have enough tests that cover the specification and all the tests pass, you are done. If you ever change the code (or the specification), then you rerun the tests.

For example, here is my specification for a program, SQR, to square a number:

1. SQR(i) SHALL return the square of *i*, so long as the result doesn't overflow a 32-bit number.
2. The program SHALL return -1 if the square of the number would overflow.

The first test, TEST_THAT_SQR_2_IS_4, runs SQR(2) and then asks the question "Is the result 4?" The function prints OK or FAIL depending on whether the answer is TRUE or FALSE. It will also print an informational message. (The full code is on GitHub; Listing 4-1 shows the parts related to TDD.)

Listing 4-1. Spin Program to Demonstrate TDD (ch04/tdd 0.spin)

```
' set up clock here - more on that later
...

PUB MAIN

  'Initialize the Terminal and TDD here - more on that later
...

  " run the tests
  TEST_THAT_SQR_2_IS_4
  TEST_THAT_SQR_BIG_IS_NEG1
  TEST_THAT_SQR_NEG_BIG_IS_NEG1

PUB SQR(x)
  return x*x

```

```
17  PUB TEST_THAT_SQR_2_IS_4 | t0
18    t0 := 4 == SQR (2)
19    TDD.ASSERT_TRUTHY(t0, string("Test that SQR (2) == 4"))
20
21  PUB TEST_THAT_SQR_BIG_IS_NEG1 | t0
22    t0 := -1 == SQR(1<<30)
23    TDD.ASSERT_TRUTHY(t0, string("Test that SQR(big) == -1"))
24
25  PUB TEST_THAT_SQR_NEG_BIG_IS_NEG1 | t0
26    t0 := -1 == SQR(-(1<<30))
27    TDD.ASSERT_TRUTHY(t0, string("Test that SQR(-big) == -1"))
```

- **Lines 11–13:** Calls to the testing methods.
- **Lines 15–16:** The method under test, `SQR`.
- **Lines 18–20:** A method to test that 2×2 == 4. `t0` will be true if `SQR(2)` returns 4. The method `TDD.ASSERT_TRUTHY` takes two arguments: `t0` and a string. It prints out the string and then either `OK` or `FAIL` depending on whether `t0` is true or false.
- **Lines 22–28:** Two additional tests.

TDD is simply a formal layer over what people do in an *ad hoc* manner when programming. You write your code and run it with some example inputs and verify that it works. With TDD, that process is *saved with the code* that you are developing and can (and should) be rerun every time you make changes to the code. Ideally, you are striving for 100 percent *coverage*, where the tests traverse all the lines of code that you have written by appropriately setting the inputs. By convention, the tests are simple and test a small piece of the code. By running all the tests, you hope to cover all the lines of the program under test. Also, by convention, the test names are verbose and grammatical so that they are self-documenting.

Let's run the tests. As you can see, there is a problem with the code. The tests are written to meet my specification, but the code fails some of my tests. It passes the test to square a small number but not to square a large one.

```
Propeller Version 1 on /dev/cu.usbserial - A103FFE0
Loading tdd_0 . binary to hub memory
4308 bytes sent
Verifying RAM ... OK
[Entering terminal mode. Type ESC or Control -C to exit.]

Test that SQR (2) == 4
... ok
Test that SQR(big) == -1
*** FAIL
```

The test for overflow after multiplication has failed. Let's modify SQR so that it passes those tests. Spin has two forms of multiplication. The standard from, *, will restrict the result to 32 bits. The alternative form, **, will return the upper 32 bits of the multiplication.

```
PUB SQR(x) | t
  t := x ** x ' multiply and return high long
  if t
    return -1
  return x*x
```

Let's rerun the tests and ensure that all the tests pass.

```
Test that SQR (2) == 4
... ok
Test that SQR(big) == -1
```

```
... ok
Test that SQR(-big) == -1
... ok
```

4.1 TDD Spin Code

The TDD Spin library is quite simple (see Listing 4-2). Define variables local to TDD (debugging port, number of tests run, etc.) and then print out the message and test result.

Listing 4-2. TDD Library (libs/TestDrivenDevelopment.spin)

```
{ TestDrivenDevelopment .spin: Test Driven Development }

VAR
    byte debug, nTest, nPass, nFail

OBJ
  UARTS : " FullDuplexSerial4portPlus_0v3 " '1 COG for 3 ↵
  serial ports

DAT
  OK byte "... ok", 13, 10, 0
  FAIL byte "*** FAIL", 13, 10, 0

PUB INIT(debugport)
    debug := debugport
    nTest := nPass := nFail := 0

PUB ASSERT_TRUTHY(condition, msg)
    nTest++
    UARTS.PUTC(debug, 13)
    UARTS.PUTC(debug, 10)
    UARTS.STR(debug, msg)
    UARTS.PUTC(debug, 13)
    UARTS.PUTC(debug, 10)
    'UARTS.DEC(debug, t)
    if condition <> 0
       UARTS.STR(debug, @OK)
       nPass++
       return TRUE
    else
       UARTS.STR(debug, @FAIL)
       nFail++
       return FALSE

PUB SUMMARIZE
  UARTS.STR(DEBUG, string(" Tests Run: "))
  UARTS.DEC(DEBUG, nTest)
  UARTS.PUTC(DEBUG, 13)
  UARTS.PUTC(DEBUG, 10)
  UARTS.STR(DEBUG, string(" Tests Passed : "))
  UARTS.DEC(DEBUG, nPass)
  UARTS.PUTC(DEBUG, 13)
  UARTS.PUTC(DEBUG, 10)
  UARTS.STR(DEBUG, string(" Tests Failed : "))
  UARTS.DEC(DEBUG, nFail)
  UARTS.PUTC(DEBUG, 13)
  UARTS.PUTC(DEBUG, 10)
```

- **Lines 3–4:** Variables local to TDD that are set/reset by the `INIT` method.
- **Lines 9–11:** A data block in which you reserve memory for the message strings. These are used over and over again, and rather than generate them each time, you can define and declare them once. The symbol `OK` is a series of bytes made of the ASCII characters for …`ok` and `CR` and `LF` (carriage return and line feed, respectively). The final 0 informs the printer that the string terminates here.
- **Lines 13–15:** Initialize the variables.
- **Lines 17–32:** Print out the message and either `OK` or `FAIL`. In line 26 and line 30, I pass the address of the memory space I reserved in the `DAT` section. `UARTS.STR` will print out the bytes at `@OK` or `@FAIL` up to the terminating `NULL (0)`.
- **Lines 34–46:** Print out a summary.

4.2 Summary

In Test-Driven Development, you first write the specification. Next, you write a test to exercise one part of the specification. It will fail. So, you write the code to allow the test to pass. When it passes, you write another test and the associated code, and so on. By the end, you should have tests that fully represent the specification, and you should have code that passes all the tests. If you so much as add a comment, you rerun all the tests!

If you ever change your specification, then you write new tests to cover those changes. If you ever change the code (be it ever so trivial a change!), rerun the tests. In collaborative projects, this is particularly important. When different people submit their updated code, the tests can be run automatically, and any failed tests are immediately apparent. This is called *continuous integration* and is aimed at reducing the manual labor of merging many different workers.

Now that we have a testing framework in place, shall we plow on? Figure 4-1 shows the work needed to clear a path forward.

Figure 4-1. *Train in snowdrift, Bernina Railway, Switzerland. Source: CJ Allen, The Steel Highway, 1928.*

CHAPTER 5

Compression in Spin

In this chapter, we will implement the compressor and decompressor purely in Spin using Test-Driven Development (TDD) methods. Rather than jumping straight into a PASM implementation, starting with a Spin version lets us ease into the problem and also debug more effectively. Once we have a working algorithm in Spin, we will translate it to PASM. In addition, a Spin version can act as a simulator to produce compressed data streams that the PASM decompressor will have to successfully operate on, and vice versa.

5.1 Structure of the Project

There will be two spin files: `steim_spin0.spin` and `steim_spin0 Demo.spin`. The file `steim_spin0.spin` is where the actual compressor and decompressor are implemented as a separate object. The file `steim_spin0 Demo.spin` is the driver file with the `MAIN` entry point into the code, as well as where the testing methods are defined. In addition, ensure that the file `TestDrivenDevelopment.spin` is in the same directory. Your directory should look like this:

```
ch5/
 ├── steim_spin0_Demo.spin
 ├── steim_spin0.spin
 ├── TestDrivenDevelopment.spin
 ├── FullDuplexSerial4portPlus_0v3.spin
 └── Numbers.spin
```

5.2 Goals of This Chapter

In this chapter, we will write the Steim compressor and decompressor in Spin. Remember, we have an array of `long` samples (4 bytes each) called `sampsBuf`. The compressor will produce a `byte` array, `packBuf`, which contains the packed or compressed data. We want to do the following:

- Start the process by copying 3 bytes from `sampsBuf[0]` to `packBuf`. This is done just once to initialize the compressor.
- Take the difference of `sampsBuf[1] - sampsBuf[0]`. If that difference fits in 1 byte, then put that 1 byte in `packBuf`. If that difference is 2 bytes, put those 2 bytes in `packBuf`, and if that difference is 3 bytes, put those 3 bytes into `packBuf`.
- Store a 2-bit code in `comprCodeBuf` that reflects which of three things we did.
- Do the previous two steps repeatedly for all the samples (Figure 5-1 shows an example of a real-world "loop").

Figure 5-1. *The Loop, Agony Point, Darjeeling Hill Railway, 1880. Photo uploaded by Bourne and Shepherd; artist unknown. Public domain.*

5.3 First Iteration

Begin by copying the template `spin_template.spin` and saving it as `steim_spin0_Demo.spin`. Listing 5-1 is the *driver* program that sets up the Propeller and then runs the tests to exercise the code. Make the changes shown in the file.

Listing 5-1. steim_spin0_Demo: First Iteration of Implementing the Compression in Spin

```
OBJ
  UARTS      : " FullDuplexSerial4portPlus_0v3 "
  NUM        : " Numbers "
  STEIM : " steim_spin0 "                  ' <<
  TDD : " TestDrivenDevelopment "          ' <<

CON
  NSAMPS_MAX = 128                         ' <<

VAR
  byte mainCogId, serialCogId
  byte comprCogId                          ' <<
  byte packBuf[NSAMPS_MAX<<2]              ' <<

  long nsamps, ncompr                      ' <<
  long sampsBuf[NSAMPS_MAX]                ' <<
  long comprCodeBuf[NSAMPS_MAX>>4]         ' <<

PUB MAIN
    mainCogId := cogid
    LAUNCH_SERIAL_COG
    PAUSE_MS(500)

    UARTS.STR(DEBUG, string(CR, " Compression ", CR, LF))
    UARTS.STR(DEBUG, string(" mainCogId: "))
    UARTS.DEC(DEBUG, mainCogId)
    UARTS.PUTC(DEBUG, CR)
    UARTS.PUTC(DEBUG, LF)
```

```
29      STEIM.INIT(NSAMPS_MAX)                 ' <<
30      TDD.INIT(DEBUG)                        ' <<
31      TEST_THAT_SAMP0_IS_PROPERLY_PACKED     ' <<
32      TDD.SUMMARIZE                          ' <<
33
34  PRI TEST_THAT_SAMP0_IS_PROPERLY_PACKED | t0, nc
35    nsamps := 1
36    sampsBuf[0] := $AB_CD_EF
37    nc := STEIM.COMPRESS(@sampsBuf, nsamps, @packBuf, ↩
      @comprCodeBuf)
38    t0 := nc <> -1
39    t0 &= (packBuf[0] == sampsBuf[0] & $FF)
40    t0 &= (packBuf[1] == sampsBuf[0] >> 8 & $FF)
41    t0 &= (packBuf[2] == sampsBuf[0] >> 16 & $FF)
42    TDD.ASSERT_TRUTHY(t0, string("Test that samp0 is properly ↩
      packed"))
```

- **Lines 15–17:** Declare the arrays where the packed samples will be stored (packBuf), the samples themselves (sampsBuf), and where the compression codes will be stored (comprCodeBuf). I know that packBuf will be at most four times the length of NSAMPS_MAX and that comprCodeBuf will be 1/16th that length.
- **Lines 30–31:** Initialize the STEIM and TDD objects.
- **Lines 32–33:** Run the test and finish.
- **Lines 36–38:** Perform the compression for a single sample.
- **Lines 39–42:** Verify whether the output is as we expect.
- **Line 43:** Perform the test and print the results.

Add all the lines marked with '<< and add the method TEST_THAT_SAMP0_IS_PROPERLY_PACKED. Lines 4–5 add the STEIM and TDD objects. From now on, any method in the file steim_spin.spin can be called by STEIM.METH_NAME. Similarly, any constant in that file is STEIM#CONSTANT_NAME. Lines 13–17 declare the new variables that will be needed by the compression and the new arrays where the uncompressed samples live before compression (sampsBuf) and where the compressed bytes live (packBuf).

Finally, in lines 30–31 the two objects are initialized, and in line 32, the first test is run. By convention, tests begin with the word TEST and are descriptive and grammatical. The test method itself is in lines 35–43. Finally, the SUMMARIZE method is called that prints out the number of tests run, the number that succeeded, and the number that failed.

The test is simple: set sample 0 to a known value, call the compression routine, and verify that the compressed data in packBuf is correct. The returned value from COMPRESS is the number of bytes in packBuf or -1 if there is an error; if there is no error, packBuf and comprCodeBuf are modified.

Listing 5-2 shows the code that does the actual work.

Listing 5-2. steim_spin0.spin: First Iteration of the Compression Code

```
CON
    CODE08 = %01
    CODE16 = %10
    CODE24 = %11
VAR
    long _nsmax

PUB INIT(nsmax)
" Set the max length of the input samples array
    _nsmax := nsmax

```

```
PUB COMPRESS(psampsBuf, ns, ppackBuf, pcomprCodesBuf) : ncompr
" Inputs :
"   psampsBuf - address of sampsBuf array (long array).
"   ns - length of 'sampsBuf' (number of samps to compress).
"   ppackBuf - address of 'packBuf' array (byte array) where
"              samples are to be packed.
" pcomprCodesBuf - address of array of compresion codes
"                  (long array) - 16 codes per long.
" Output :
"   ncompr - length of packed array (bytes)
    if ns == 0 'this isn't an error - but do nothing
        return 0

    if (ns < 0) | (ns > _nsmax)
        return -1

    ' handle sample0 first - it is always packed to
    ' 3 bytes regardless of its size
    bytemove(ppackBuf, psampsBuf, 3)
    ncompr := 3
    long[pcomprCodesBuf] := CODE24

    if ns == 1
        return ncompr
    return -1
```

- **Lines 1–4:** Constants that define the compression codes.
- **Lines 8–10:** The initialization routine. Save a local version of `NSAMPS_MAX`.
- **Lines 12–21:** The compression method, along with comments detailing what the inputs and outputs are.
- **Lines 22–26:** Check the inputs.
- **Lines 30–32:** Perform the compression for the first sample.
- **Lines 34–35:** Return in the case of $N \equiv 1$.
- **Line 36:** Otherwise, return an error.

The actual compression is simple. We copy the three low bytes of `sampsBuf[0]` to `packBuf[0]-packBuf[2]`, we set the compression code to reflect that this is a 3-byte packing, and we return the number 3. The calling code for `COMPRESS` is as follows:

```
nc := STEIM.COMPRESS(@sampsBuf, nsamps, @packBuf,
@comprCodeBuf)
```

The method definition is as follows:

```
PUB COMPRESS(psampsBuf, ns, ppackBuf, pcomprCodesBuf) : ncompr
```

`MAIN` passes in the *addresses* of the arrays; in particular, it passes the memory location of the first element of each array (`@sampsBuf`). The method definition saves those addresses as `psampsBuf`, and so on.

5.4 Passing Arrays to Methods

The compression method in the `STEIM` object must access the arrays `sampsBuf`, `packBuf`, and `comprCodeBuf`. To do so, it needs the address in hub memory where each of them is stored. The calling method is written thusly:

```
nc := STEIM.COMPRESS(@sampsBuf, nsamps, @packBuf,
@comprCodeBuf)
```

The symbol `@sampsBuf` is shorthand for "address of the first byte of the first sample of the `sampsBuf` array."

The definition of the called method in the `STEIM` object is as follows:

```
PUB COMPRESS(psampsBuf, ns, ppackBuf, pcomprCodesBuf) : ncompr
```

Here the variable `psampsBuf` holds that address. To access that data, we must inform the compiler that the variable is an address (rather than a value). In other words, to access the i-th sample (`sampsBuf[i]`), we must say `long[psampsBuf][i]`. Similarly, `ppackBuf` holds the address of the byte array `packBuf`, and it must be accessed as `byte[ppackBuf][i]`. To copy data from `sampsBuf` to `packBuf`, we must do something like the following:

```
bytemove(ppackBuf, psampsBuf, 3)
```

Here, 3 bytes are copied from the address `psampsBuf` (which is the address of the start of that array) to the address `ppackBuf` (which is the address of the start of the `packBuf` array).

The `bytemove` command copies 3 bytes from memory location `psampsBuf` to memory location `ppackBuf` (a `longmove` command would have moved 3 longs).

The expression `long[pcomprCodeBuf] := CODE24` says to treat the address `pcomprCodeBuf` as a long and to write to all 4 bytes following that address.

A function/method definition in Spin looks like this:

```
VAR
  long globalVar

PUB MYFUN(arg1, arg2) : retVal | localVar
  ' globalVar is available for use and can be modified
  ' globalVar changes will be seen outside the function
  '
  ' use arg1 and arg2 inside the function
  '
  ' localVar is available here and is local to the
  ' function. It isn't available outside the function.
  '
  ' set the return value retVal
return ' this will return retVal to the calling program
```

The arguments `arg1` and `arg2`, the return value `retVal`, and the local variable `localVar` are all optional.

5.5 Testing

Here are the tests that I run. As I was developing the code, I started out with the simpler tests (testing that sample 0 was packed correctly and then sample 1) and moved to successively more complex tests (sample 15, and so on).

```
TEST_THAT_SAMP0_IS_PROPERLY_PACKED
TEST_THAT_SAMP0_SETS_NCOMPR_CORRECTLY
TEST_THAT_SAMP0_SETS_COMPRCODE_CORRECTLY
TEST_THAT_COMPRESSOR_FAILS_FOR_NSAMPS_WRONG
```

```
TEST_THAT_SAMP1_IS_PROPERLY_PACKED_ONE_BYTE
TEST_THAT_SAMP1_IS_PROPERLY_PACKED_TWO_BYTES
TEST_THAT_SAMP1_IS_PROPERLY_PACKED_THREE_BYTES
TEST_THAT_SAMP1_SETS_COMPRCODE_CORRECTLY
TEST_THAT_SAMP1_SETS_COMPRCODE_CORRECTLY_TWO_BYTES
TEST_THAT_SAMP15_PACKS_PROPERLY
TEST_THAT_SAMP16_PACKS_PROPERLY
TEST_THAT_SAMP127_PACKS_PROPERLY

TEST_THAT_SAMP0_IS_PROPERLY_UNPACKED
TEST_THAT_SAMP1_IS_PROPERLY_UNPACKED
TEST_THAT_128_SAMPS_PROPERLY_COMPRESS_AND_DECOMPRESS
```

I built up the code by writing the test and then writing the code that lets the test succeed. As I built up the code bit by bit, I made sure *all* the tests were run every time I modified the program and that they all passed.

```
$ propeller-load -t -r -p /dev/cu.usbserial-A103FFE0 steim_
spin_Demo.binary
Propeller Version 1 on /dev/cu.usbserial-A103FFE0
Loading steim_spin_Demo.binary to hub memory
7568 bytes sent
Verifying RAM ... OK
[Entering terminal mode. Type ESC or Control-C to exit.]
Compression
mainCogId:     0

Test that sample 0 is properly packed to packBuf
...ok

<<<...output deleted...>>>

Test that compression and decompression of 128 random numbers
is successful
...ok
```

```
Tests Run: 20
Tests Passed: 20
Tests Failed: 0
```

5.6 Final Code

I won't go through the compression and decompression routines in detail because the focus of this book is on PASM (and they are quite self-explanatory). However, I reproduce them here because I'll refer to them when I am developing the PASM code.

5.6.1 Compression in Spin

The full compression code first checks that the inputs are correct. Next, the first sample is compressed, and then the remaining samples are differenced and compressed. The driver file (`steim_spin1_Demo.spin`) will call the code in Listings 5-3 and 5-4 (which are in file `steim_spin1.spin`).

Listing 5-3. steim spin1.spin: Complete Compressor Code Listing

```
PUB COMPRESS(psampsBuf, ns, ppackBuf, pcomprCodesBuf) : ↩
ncompr | j, diff, adiff, codeIdx, codeShift
'' Inputs :
''   psampsBuf - address of sampsBuf array (long array).
''   ns - length of `sampsBuf ` (number of samps to compress).
''   ppackBuf - address of `packBuf ` array (byte array) where
''                samples are to be packed.
'' pcomprCodesBuf - address of array of compresion codes
''                    (long array) - 16 codes per long.
'' Output :
```

```
"   ncompr - length of packed array (bytes)
    if ns == 0 ' this isn't an error - but do nothing
        return 0

    if (ns < 0) | (ns > _nsmax)
        return -1

    ' handle sample0 first - it is always packed to 3 bytes
    ' regardless of its size
    bytemove(ppackBuf, psampsBuf, 3)
    ncompr := 3
    long[pcomprCodesBuf] := CODE24

    if ns == 1
        return ncompr

    repeat j from 1 to ns -1
        diff := long[psampsBuf][j] - long[psampsBuf][j -1]
        adiff := || diff
        codeIdx := j / 16
        codeShift := (j // 16) * 2
        if adiff < $7F
            bytemove(ppackBuf + ncompr, @diff, 1)
            ncompr++
            long[pcomprCodesBuf][codeIdx] |= CODE08 << ➥
            codeShift
        elseif adiff < $7FFF
            bytemove(ppackBuf + ncompr, @diff, 2)
            ncompr += 2
```

```
38                long[pcomprCodesBuf][codeIdx] |= CODE16 << ↩
                  codeShift
39             else
40                bytemove(ppackBuf + ncompr, @diff, 3)
41                ncompr += 3
42                long[pcomprCodesBuf][codeIdx] |= CODE24 << ↩
                  codeShift
43
44       return ncompr
```

- **Lines 11–21:** Verify inputs and compress sample 0.
- **Line 27:** Form the backward difference $\delta_j = s_j - s_{j-1}$.
- **Line 28:** Calculate the absolute value $a_j = |\delta_j|$.
- **Lines 29–30:** The compression codes are 2 bits each, so the codes for samples s_j , j = 0–15 are in `comprCodesBuf[0]`, the codes for samples s_j , j=16–31 are in `comprCodesBuf[1]`, and so on. The j-th code is shifted by (j mod 16) × 2 bits.
- **Lines 31-42:** Depending on whether a_j fits in 1, 2, or 3 bytes, place the difference in `packBuf` and place the code in `comprCodeBuf`.

5.6.2 Decompression in Spin

The decompression is a little more involved, mainly because negative numbers have to be sign-extended properly. The general outline is the same as for compression: handle the first sample and then loop through the remaining samples.

Listing 5-4. steim_spin.spin: Spin Decompression Method

```
PUB DECOMPRESS(psampsBuf, ns, ppackBuf, ncompr, pcomprCodesBuf) : ndecomp | diff, pkIdx, codeIdx, codeShift, theComprLong, jcomprCode, pkBytes, shneg
" Inputs :
"   psampsBuf - address of sampsBuf array
"   ns - length of 'sampsBuf' (number of samps to decompress)
"   ppackBuf - address of 'packBuf' array where samples are packed
"   ncompr - length of packBuf
"   pcomprCodesBuf - array of compresion codes (16 codes per long)
" Output :
"   ndecomp - number of samples decompressed (should be same as ns)

    ' check inputs
    if ns == 0 ' this isn't an error - but do nothing
        return 0

    if (ns < 0) | (ns > _nsmax)
        return -1

    ' init
    ndecomp := 0
    pkIdx := 0

    repeat while ns > ndecomp
        ' codeIdx - index into the comprCodesBuf array
        ' codeShift - index into the actual code long where
        '   the code for this sample is stored
        codeIdx := ndecomp / 16
        codeShift := ( ndecomp // 16) * 2

        theComprLong := long[pcomprCodesBuf][codeIdx]
        jcomprCode := (theComprLong >> codeShift) & %11
        case jcomprCode
            CODE08 :
                bytemove(@diff, ppackBuf + pkIdx, 1)
                diff <<= 24 ' sign extend
                diff ~>= 24
                pkBytes := 1
            CODE16 :
                bytemove(@diff, ppackBuf + pkIdx, 2)
                diff <<= 16 ' sign extend
                diff ~>= 16
                pkBytes := 2
            CODE24 :
                bytemove(@diff, ppackBuf + pkIdx, 3)
                diff <<= 8 ' sign extend
                diff ~>= 8
                pkBytes := 3

        pkIdx += pkBytes
        ncompr -= pkBytes

        if ndecomp == 0 ' samp 0 is packed as is - not a difference
            theSamp := diff
        else
            theSamp := long[psampsBuf][ndecomp -1] + diff

```

```
56          theSamp <<= 8
57          theSamp ~>= 8
58          long[psampsBuf][ndecomp] := theSamp
59          ndecomp++
60
61          if ncompr < 0 ' error check on ncompr
62              return -1
63      return ndecomp
```

- **Lines 26–30:** Determine the compression code for this sample by getting the correct long from the `comprCodesBuf` array and then getting the appropriate 2 bits.

- **Lines 31–46:** Copy the difference bytes (either 1, 2, or 3, depending on the compression code for this sample) from `packBuf` and *sign-extend* them to form a proper 32-bit δ_j. The operations `diff <<= 24` and `diff ~>= 24` will first shift the low byte up to the high byte location and then do an *arithmetic* shift back to the low byte. An arithmetic shift retains the sign of the byte. So, if the low byte was a negative 1-byte number (-127 to -1), then the 32-bit number would still be negative (with 1s in all the high bits).

- **Lines 51–58:** Form the sample $s_j = s_{j-1} + \delta_j$ and sign-extend.

As we build up the PASM code, we have to reproduce each of these steps, including the loops.

5.7 The Need for Speed

The main reason to implement the code in PASM is to speed it up. Let's see how much time the compression and decompression take in Spin. Listing 5-5 shows the timing code in the driver file `steim_spin1_Demo.spin`.

Listing 5-5. Measuring the Timing of Compression

```
PUB MAIN | t0, dt, j
...
  ' time
  nsamps := 128
  repeat j from 0 to nsamps-1
    sampsBuf[j] := j * 50000

  t0 := cnt
  nc := STEIM.COMPRESS(@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf)
  dt := cnt - t0
  UARTS.STR(DEBUG, string(" nc= "))
  UARTS.DEC(DEBUG, nc)
  UARTS.PUTC(DEBUG, CR)
  UARTS.STR(DEBUG, string(" dt= "))
  UARTS.DEC(DEBUG, dt)
  UARTS.PUTC(DEBUG, CR)
  UARTS.STR(DEBUG, string(" dt(ms) ~ "))
  UARTS.DEC(DEBUG, dt / ONE_MS)
  UARTS.PUTC(DEBUG, CR)
...
```

Running this code prints out the following:

```
...
nc= 382
dt= 1526096
dt (ms) ~ 19
```

Here, nc is the number of bytes in the compressed buffer packBuf, and the two dt values are the time taken to perform the compression (in clock cycles and milliseconds, respectively).

If your application is OK with taking 20ms to compress 128 samples, then you can stop right here. If not, let's estimate how much of a speedup we can expect in PASM.

5.7.1 Timing in PASM

Each instruction in PASM takes a fixed number of clock cycles that are documented in the manual. Almost all the instructions take four clock cycles exactly.[1]

A clock cycle is 12.5ns (when the system clock is running at 80MHz), so typically instructions require 50ns to complete.

The system clock is determined by the constants shown in Listing 5-6 in the main Spin file.

Listing 5-6. Clock Mode Settings

```
CON ' Clock mode settings
  _CLKMODE = XTAL1 + PLL16X
  _XINFREQ = 5_000_000
```

[1]There are exceptions. Hub operations (rdlong, for example) take between 8 and 23 clock cycles. There are a small number of other exceptions. The manual lists the timing for each instruction.

`_XINFREQ` is the frequency of the external crystal. The `_CLKMODE` variable sets the clock to 16 times the crystal frequency (in this case, 80MHz).

5.7.2 PASM Timing Estimate

During the compression, there is some setup, and then all the samples are processed.

For each of the 128 samples, something like the following must happen:

- Read a sample from the hub (~20 clock cycles).
- Subtract from the previous one (~5 instructions, ~20 cycles).
- Take the absolute value (~5 instructions, ~20 cycles).
- Check for the length of the absolute value (~10 instructions, ~40 cycles).
- Calculate the compression code location (~5 instructions, ~20 cycles).
- Write up to 3 bytes to the hub (~60 cycles).

The initialization and finalization may look something like this:

- Initialize the variables (~10 instructions, ~40 cycles).
- Take care of the overhead, in other words, writing the compression code to the hub every 16 samples, or 8 times for 128 samples (~20 cycles × 8 ~ 160 cycles).

The total is approximately 25,000 clock cycles, or 0.3ms (with an 80MHz clock). This is a speedup factor of 60, so if the data rates in your application are high, it will be worth going to the trouble of implementing it in PASM (in Figure 5-2, I show an example of things that go at different speeds!).

Figure 5-2. *Bullock cart in front of Victoria Terminus ("The most magnificent railway station in the world," Bombay, India, 1903.* `https://upload.wikimedia.org/wikipedia/commons/f/f4/Victoriaterminus1903.JPG`.

5.8 Summary

In this chapter, we worked through a full example of using Test-Driven Development to build and verify a Steim compressor and decompressor. The code is pure Spin, with a driver file (with a `Demo` suffix) and a worker file with functions (also known as *methods*) that are called from the driver. The tests are in the driver file, and each one exercises one small part of the specification.

I showed how a function/method is defined and called, how to test the inputs for reasonableness, how to copy bytes out of a `long`, and how to correctly copy them back in during decompression. I discussed how to pass variables and arrays to a Spin function and how to get a return value.

Finally, you learned how measure the time taken to process an array.

PART II

Spin and PASM

CHAPTER 6

Propeller Assembler: PASM

Now that we are all up to speed on Spin, let's plunge into PASM. Here I introduce the form and structure of PASM cogs and the details of PASM instructions.

In addition, I spend some time talking about how to pass information from the main cog (generally the driver program in Spin) to the PASM cogs. In this chapter and the next one, we will need to pass all the same variables (`nsamps`, `sampsBuf`, etc.) to the PASM cog as we did in the Spin version.

Remember, the cogs are almost completely independent of each other. To communicate between two of them, they have to agree on a location in hub memory where the shared information is kept. In addition, each cog has to continually check that location in case the other one has changed it.

Passing parameters between Spin programs is easy.

```
...
PUB MAIN
    retval := MYFUN(x, y, @z)

PUB MYFUN(funx, funy, funzPtr) : funret
   ...
   funret := ...
   return funret
```

S. Anandakrishnan, *Propeller Programming*, https://doi.org/10.1007/978-1-4842-3354-2_6

We simply place a list of the variables in the call (`MYFUN(x, y, @z)`), and those variables are available in the function body. Similarly, the function can return a number (`funret`), which is available in the main program.

It is more complicated in PASM because the PASM code is running in a separate cog that has its own memory. Spin code affects hub memory, and Spin instructions have *implicit* access that space. PASM code running in a separate cog has to *explicitly* access hub memory. That dance is what we will focus on for the rest of the book.

There is one more subtle difference between Spin and PASM: Spin functions (`MYFUN`) spring into existence *when they are called*, and they proceed from the beginning to the end and then disappear. A PASM cog is generally started once, and then it persists forever. You have to explicitly ask it to do something and have it idle otherwise.

Once launched, a PASM cog runs independently. The only way to pass parameters back and forth to the cog is to change a variable in hub memory and to have the cog read and react to that change.

6.1 Instructions in PASM

Cog memory consists of a series of longs (up to 496 of them). Some of those longs are instructions, and some are space reserved for variables. Instructions are executed in order starting at the first one (the one marked with `ORG 0`). You can request that instead of executing the next instruction, the Propeller should jump to a different part of cog memory. The Propeller will do so and then continue to execute instructions starting there.

There are more than 100 instructions in PASM, but many of them are close cousins, so don't be intimidated by the PASM manual. For example, there are five variants of `add`, four versions of `sum`, and so on. What all the instructions have in common is that they do one simple thing to a memory location in cog memory (sometimes referred to as a *register*). They *may* also affect the special flags Z and C. That's it.

The form of a PASM instruction is as follows:

```
<label> <if-clause> instr destination, <#>source <effect>
```

Here, the items in angle braces are optional. `instr` is the PASM instruction; the destination and source numbers are 9-bit values that refer to a register address. If the source is preceded by the optional *literal operator* `#`, then the source is that 9-bit value (rather than a register address). The label, `if` clause, and effect parts of the instruction are all optional.

Listing 6-1 shows a complete PASM program to toggle a pin (this is from p. 239 of the Propeller manual, v1.2).

Listing 6-1. Toggle a Pin in PASM

```
{{ AssemblyToggle.spin }}
CON
  _clkmode = xtal1 + pll16x
  _xinfreq = 5_000_000

PUB Main
{ Launch cog to toggle P16 endlessly }
   cognew (@Toggle, 0)       'Launch new cog

DAT
{Toggle P16}
        org   0              'Begin at Cog RAM addr 0
Toggle  mov   dira, Pin      'Set Pin to output
```

```
14                mov   Time, cnt        'Calculate delay time
15                add   Time, #9         'Set minimum delay here
16  :loop         Waitcnt Time, Delay    'Wait
17                xor   outa, Pin        'Toggle Pin
18                jmp   #:loop           'Loop endlessly
19
20  Pin   long    |< 16                  'Pin number
21  Delay long    6_000_000              'Clock cycles to delay
22  Time          res 1                  'System Counter space
23  FIT 496
```

- **Lines 1–8:** The Spin program in cog 0 that launches a new cog to do the work.
- **Line 8:** The Spin command to start a new cog using the code at the address `@Toggle`.
- **Lines 10–23:** The PASM code that does the work of toggling the pin.
- **Line 13:** This line has a *label* (`Toggle`), an *instruction* (`mov`), a *destination* register, and a *source* register (`dira` and `Pin`, respectively).
- **Line 15:** This line has a *literal value* (`#9`).
- **Line 16:** This line has a label and a *process control* instruction, `waitcnt`, that pauses the cog until the counter value in `cnt` reaches the value in the register `Time`. When the counter reaches the value in the register `Time`, the processor continues to the next

expression. In addition, `waitcnt Time, Delay` will add `Delay` to `Time` and store that number in `Time`, so the next time the `waitcnt` instruction is executed, the processor will pause until time `Time + Delay`.

- **Line 18:** Another process control statement that changes the direction of execution. The instruction loops back to the instruction labeled `:loop` rather than stepping to the next instruction.
- **Lines 20–21:** Register holding data. The construct `|< 16` sets pin 16 of the register `Pin`.
- **Line 22:** Register of reserved workspace. Its value is undefined.

The new cog is loaded with nine longs. The first six longs are instructions (`mov`, `mov`, `add`, `waitcnt`, `xor`, and `jmp`); the next three longs are the data and reserved space. Execution begins with the first instruction and steps along sequentially, until it encounters the `jmp`. This is a basic program but one that captures many features of PASM. We will look at *effects* and hub interactions soon.

6.1.1 The Add Instruction

One of the most common tasks for a computer is to do arithmetic. In Spin you can write the following:

```
x += y
z++
a := b + c
```

You can do the same in PASM. Here is the add instruction:

```
' PASM version of x += y
add _cX, _cY
```

This sums the two numbers in variables _cX and _cY and places the result back into _cX.

```
' PASM version of z++
add _cZ, #1
```

Here the instruction increments the number in _cZ by 1 and places the result back into _cZ:

```
' PASM version of a := b + c
mov _cA, _cB
add _cA, _cC
```

Here we encounter the big difference between Spin and PASM. In Spin, we simply said `a := b + c`. Under the hood, two things are going on: `b` and `c` are added, and then the result is placed into `a`. In PASM, there is no "hood." We have to do those two things explicitly!

The `mov _cA, _cB` instruction moves the contents of variable _cB into _cA. Then the add instruction adds _cC to _cA and places the result back into _cA (and because we had the foresight to place _cB into _cA first, the result is as we desire).

6.1.2 The mov Instruction

The `mov` instruction sets a variable to a value.

```
' PASM version of x := y
mov _cX, _cY
```

Here we copy the contents of variable _cY to the variable _cX.

```
' PASM  version of x := 42
mov _cX, #42
```

Here we set `_cX` equal to 42. When you want to set `_cX` to a number, you have to tell PASM that by including the *literal* indicator (#). Without that, the instruction is `mov _cX, 42` (don't do this at home!), and the Propeller would try to move the contents of *memory location 42* into `_cX`—not what you wanted.

```
' PASM version of x := 31415
'mov _cX, #31415 ' NOPE NOPE NOPE won't work
mov _cX, _cPiFour
```

Unfortunately, if you want to refer to numbers larger than 511 (in other words, any number that won't fit into 9 bits), you have to first store that number into a variable and then copy the contents of that variable to where you want it.

6.1.3 Variables

Variables are longs that are stored in cog memory along with the instructions (after all the instructions). You can initialize these variables to any number (any number that will fit in a long, of course).

```
_cPiFour long 31415
r0 res 1
r1 res 1
_cArr res 8
FIT 496
```

Here we declare a name for the variable (`_cPiFour`), followed by the size of the variable (`long`), followed by the value to which that variable is initialized (`31415`). Here you don't need the literal indication (#), and you aren't limited to 9 bits.

Finally, the line `r0 res 1` reserves one long and places that address in `r0`. The form of this instruction is like this: the name of the variable (`r0`) followed by the `res` directive, followed by the number of longs to reserve.

The expression `_cArr res 8` reserves eight longs and places the address of the first long in the variable `_cArr`. Any variables you refer to in your PASM code *must* have an associated storage declaration (either a line like `_cPiFour long 31415` or a reservation line like `r0 res 1`). The PASM compiler will complain if you don't do this.[1]

The expression `FIT 496` should always come at the end of the PASM program. It validates that the previous instructions and memory allocations fit within the allowed 496 longs.

6.1.4 Effects

Most instructions can include *effects*. If you specify either `wz` or `wc`, the `Z` or `C` flags will be changed, respectively. So, for example, the `mov` instruction has the following effects (this is an excerpt from the manual page for `mov`):

```
mov Destination, <#>Value
...
```

> If the `WZ` effect is specified, the `Z` flag is set (1) if *Value* equals zero. If the WC effect is specified, the C flag is set to *Value*s MSB. The result is written to *Destination* unless the NR effect is specified.

Here are some examples:

```
mov r0, #0 wz ' set Z=1
mov r0, #1 wz ' set Z=0
neg r0, #1    ' put -1 into r0
mov r1, r0 wc ' set C=1 (msb of r0 is 1)
mov r0, #42 wz,nr ' set Z=0 (wz), but don't change r0 (nr)
```

[1] `res` lines *must* come after `long` variable declaration lines.

The value of Z or C will persist until it is next changed by a wz or wc effect in an instruction. An important use of the effect is in branching and conditional expressions where an instruction is executed based on the value of these flags.

6.1.5 Literals

The mov instruction moves a value into a destination register. The source value either can be from another register or can be a literal value.

```
mov Destination, <#>Value
```

Literals are indicated by the pound sign (#) and are limited to 9 bits.

```
mov r0, r1 ' move contents of register r1 to register r0
mov r0, #0 ' set r0=0
mov r0, #42 ' set r0=42
'mov r0, #31415 ' ILLEGAL. Literals must be less than 512
```

6.1.6 Labels

There are 496 longs of cog memory available for use. Every instruction occupies one long. An instruction can include a *label* so that you can branch to that instruction.

```
...
  mov r1, #0
  mov r0, #8
:loop
  add r1, #1
  djnz r0, #:loop

_cPiFour long 31415
r0 res 1
r1 res 1
FIT 496
```

Here the label `:loop` labels the `add` instruction so that the jump instruction (`djnz r0, #:loop`) will execute the add instruction eight times (`djnz` r0, #:`loop` means "decrement the register `r0` and jump to label `:loop` if the result is nonzero").[2]

6.1.7 Conditional Evaluation

In Spin the following is a common task:

```
' conditional evaluation
' if x is less than 100, set x to y.
if x < 100
  x := y
x++
```

As you can imagine, there is quite a bit under the hood here that will need to be done explicitly in PASM. The general scheme is this: compare a variable with a number and either jump past a section of code or don't jump past it based on the result of the comparison.

```
   cmp _cX, #100 wc
   if_nc jmp #:done
     'PASM instructions to evaluate if x < 100
   mov _cX, _cY
 :done
   add _cX, #1
```

[2]There are two types of labels: global and local. Local labels have a colon as the first character. There are rules about the use of local variables that allow you to reuse the name, but I prefer to always use unique local variable names. See p. 242 in the Propeller manual if you want to reuse local variable names.

- **Line 1:** Compare *x* to 100 and set the `C` flag if *x* < 100.

Here is the explanation for `cmp` from the manual:

> CMP (Compare Unsigned) compares the unsigned values of Value1 and Value2. The Z and C flags, if written, indicate the relative equal, and greater or lesser relationship between the two. If the WZ effect is specified, the Z flag is set (1) if Value1 equals Value2. If the WC effect is specified, the C flag is set (1) if Value1 is less than Value2.

We ask for the `wc` effect, so if *x* (Value1) is less than 100 (Value2), then the C flag will be set (C=1).

- **Line 2:** This is conditional expression that says that if the `C` flag is *not* set (`if_nc`), then execute the instruction that follows on that line (the `jmp #:done`). In our case, if *x* < 100, then the `C` flag will be set, and the jump will *not be executed*.

There are a host of `if_xx` conditional expressions. They all have similar form (see p. 244 of the Propeller manual for a complete list).

- `if_z instr`: If the `Z` flag is set, execute the instruction.
- `if_nz instr`: If the `Z` flag is *not* set, execute the instruction.
- `if_c instr`: This is the same as the previous one, but for the `C` flag.
- `if_nz_and_nc instr`: If the `Z` flag is *not* set and the `C` flag is also *not* set, then execute the instruction**...**and every possible combination of `Z`, `NZ`, `C`, `NC`, `AND`, and `OR`. As you can imagine, this gives tremendous flexibility in deciding when to do something.

I used the `cmp` instruction to set the `C` flag. Remember, every instruction gives you the option to manipulate the `Z` and `C` flags, so you can set the groundwork for the various `if_` instructions in many ways.

6.1.8 Branching

As I said earlier, the Propeller will execute instructions in order starting at the start of cog memory. It will proceed to the next instruction unless the order is interrupted by a *jump* instruction. There are two jump instructions that we will use a lot.

- `jmp #:label`: Jump to an address labeled `:label` immediately.
- `djnz r0, #:label`: Decrement the variable `r0` and jump to a label if the result is not zero.

These are used in conditional evaluation (as in the previous section) and in loops. In Spin, you would say this:

```
x := 0
repeat 8
  x++
```

In PASM, you must set up a loop variable (here `r0`) and explicitly decrement and check its value. Repeat until its value is zero.

```
1    mov r0, #8
2    mov _cX, #0
3  :loop
4    add _cX, #1
5    djnz r0, #:loop
```

In line 5, the instruction is to "decrement `r0` and jump to `:loop` if the result is not zero." After eight iterations, `r0` will be zero, and the loop is exited.

6.2 Reading the PASM Manual

PASM *instructions* are composed of (up to) four parts. For example, the instruction to move the contents of a 4-byte long from hub memory to cog memory is `rdlong` (the manual page for `rdlong` is shown in Figure 6-1).

```
rdlong _cns, _cnsPtr wz
```

The parts of the instruction are as follows:

- The action to be taken (`rdlong`).
- The destination address (`_cns`).
- The source address.
- The effect `wz`, which will affect the `Z` flag. There is also `wc`, which affects the `C` flag.
- The effect `nr`, which will prevent the instruction from actually occurring but only set the `Z` or `C` flag.

In the manual page, the important pieces of information are the succinct description of the instruction:

Instruction Read long of main memory.

Here's the summary:

RDLONG *`Value, <#> Address`*

- *`Value`* (d-field) is the register to store the long value into.
- *`Address`* (s-field) is a register or a 9-bit literal whose value is the main memory address to read from.

Here is the detailed explanation, along with a description of the `wz`, `wc`, and `nr` *effects*:

RDLONG syncs to the hub. ...If the WZ effect is specified, the Z flag will be set (1) if the value read from main memory is zero.

Finally, the time taken to execute the instruction will be stated. For most instructions, it is four clock cycles. Hub instructions take longer because of the need to sync with the other cogs.

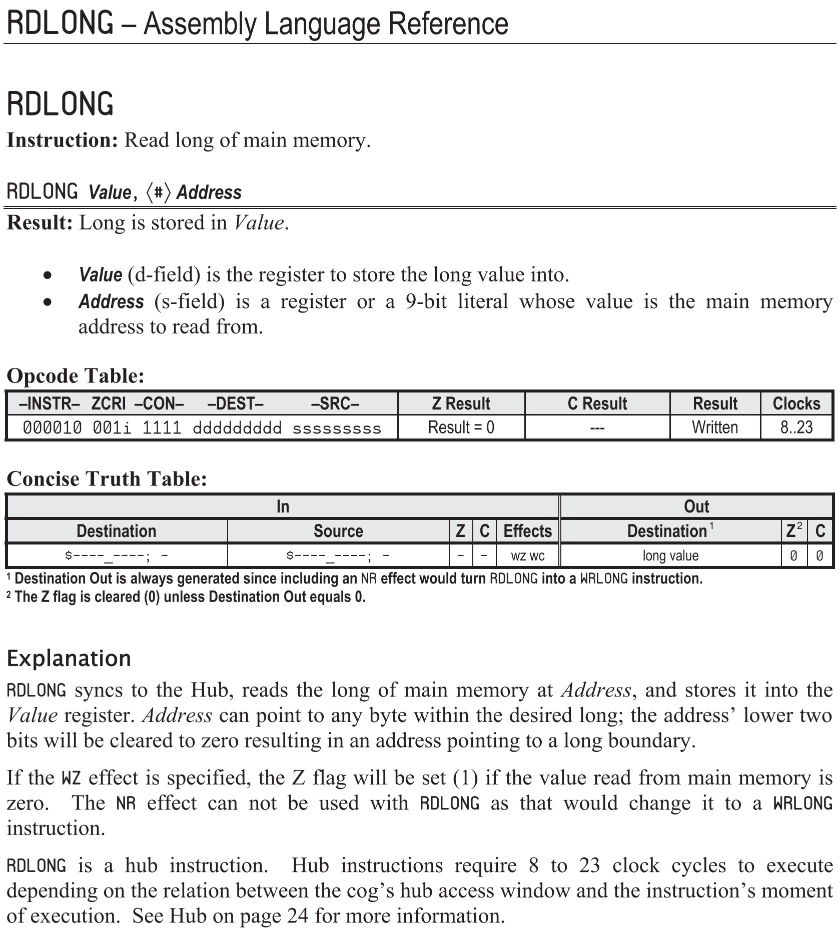
RDLONG is a hub instruction. Hub instructions require 8 to 23 clock cycles to execute....

6.3 Categories of PASM Instruction and Registers

There are a large number of PASM instructions and registers, but they fall into a small number of categories, which I summarize here.

6.3.1 Copying

The instructions in this category are used to both copy values from one memory location to another, as well as to affect the `Z` and `C` flags. The instruction `mov d, <#>s <wz> <wc>` will move the source (either the contents of register `s` or the value `#s`) into register `d`. If the source value is zero and the `wz` effect is specified, then set the `Z` flag. If the `wc` effect is specified, then the `C` flag is set to the source's MSB (either 0 or 1).



RDLONG – Assembly Language Reference

RDLONG

Instruction: Read long of main memory.

RDLONG ***Value***, ⟨#⟩ ***Address***

Result: Long is stored in *Value*.

- ***Value*** (d-field) is the register to store the long value into.
- ***Address*** (s-field) is a register or a 9-bit literal whose value is the main memory address to read from.

Opcode Table:

–INSTR– ZCRI –CON– –DEST– –SRC–	Z Result	C Result	Result	Clocks
000010 001i 1111 ddddddddd sssssssss	Result = 0	---	Written	8..23

Concise Truth Table:

In					Out		
Destination	Source	Z	C	Effects	Destination[1]	Z[2]	C
$----_----; -	$----_----; -	-	-	wz wc	long value	0	0

[1] Destination Out is always generated since including an NR effect would turn RDLONG into a WRLONG instruction.

[2] The Z flag is cleared (0) unless Destination Out equals 0.

Explanation

RDLONG syncs to the Hub, reads the long of main memory at *Address*, and stores it into the *Value* register. *Address* can point to any byte within the desired long; the address' lower two bits will be cleared to zero resulting in an address pointing to a long boundary.

If the WZ effect is specified, the Z flag will be set (1) if the value read from main memory is zero. The NR effect can not be used with RDLONG as that would change it to a WRLONG instruction.

RDLONG is a hub instruction. Hub instructions require 8 to 23 clock cycles to execute depending on the relation between the cog's hub access window and the instruction's moment of execution. See Hub on page 24 for more information.

Figure 6-1. *Manual page for rdlong*

6.3.2 Arithmetic

There are a number of math instructions to take the absolute value, add or subtract two numbers, or negate a number. There are variants of each of these that do slightly different things based on the value of flags.

- The `add` instruction adds the *unsigned* values in the destination and source and places the result in the destination register. By contrast, `adds` treats the values as signed numbers. The instructions `addx` and `addsx` are *extended* additions that let you do multilong addition (for example, 64-bit addition; see the manual for details).
- There are a similar set of subtraction instructions (`sub`, `subs`, `subabs`, etc.)
- The `neg` instruction negates a number; `negc` does so if `C=1`; `negnc` does so if `C=0`; and `negz` and `negnz` negate based on the value of the `Z` flag.

6.3.3 Boolean, Comparison, and Bit-Shift Operators

These instructions operate bitwise.

- The Boolean instructions `and`, `or`, and `xor` perform the bitwise *and*, *or*, and *exclusive or* of the destination and the source, placing the result in the destination register. `test` performs an *and* but doesn't store the result in the destination; this is usually done to affect the flags.
- The comparison operator `cmp d, s` compares the destination and the source (treating them as unsigned values). If the `wz` effect is specified, then `Z=1` if `d=s`. If the `wc` effect is specified, then `C=1` if `d<s`. There are other comparison instructions (`cmps`, `cmpsub`, `cmpsx`, etc.) that compare signed values or compare and subtract, and so on.

- The `min` and `max` operators store the greater or lesser of the source and destination in the destination register, respectively.

There are a number of bit-setting and shifting operators.

- The `mux...` family of operators sets the destination register based on two things: the high bits in the source and the value of either `C` or `Z`. Thus, `muxc d, #5` will set bits 2 and 0 (because `#5 = b0101`) of the destination register `d` to the value of the flag `C`. The other bits in `d` are unaffected. The other members of this family are `muxnc`, `muxz`, and `muxnz`.

The bit shifting operators are as follows:

- **Reverse:** `rev d`, `s` reverses the lower 32 – *s* bits of `d` and stores the result in `d`. So, if *s* = 24, then reverse the lower 8 bits of `d` and clear the upper 24 bits. Store this result back into `d`.
- **Rotate:** `rol d`, `s` rotates the destination register (`d`) left by `s` bits, placing the MSBs rotated out of `d` into its LSBs. Similarly, `ror` will rotate right. By contrast, `rcl d`, `s` also rotates the register `d` left but fills the LSBs with the value of `C. rcr` does the same for rightward rotation.
- **Shift:** `shl d`, `s` shifts `d` left by `s` bits. The new LSBs are set to zero. Similarly, `shr` shifts right.
- **Shift arithmetic:** `sar d`, `s` shifts `d` right by `s` bits, extending the MSB. In other words, the value of MSB will be copied into all the shifted bit locations. Thus, `sar d, #8` will set the upper 8 bits to either 1 or 0 depending on the original value of the MSB of `d`. The lower 24 bits of `d` are the result of the shift.

6.3.4 Process Control

Process control instructions will either pause the processor until a condition is met or alter the sequence of execution.

The `waitcnt t, dt` instruction will pause execution until the internal counter `cnt` is equal to the value in `t`. When the two are equal, the value of `t` will be set to `t+dt`, and the processor will step to the next instruction. Because `cnt` is a 32-bit register that rolls over, the pause from the `waitcnt` instruction will eventually end, but it could take up to 4 billion counts (about 53 seconds at 80MHz clock) if `t` happens to be less than the current value of `cnt`.

The reason that the time register `t` is incremented by `dt` is to allow for regular and deterministic delays in the program. With this mechanism, regardless of when you call `waitcnt`, the program will step every `dt` seconds.

The instruction `waitpeq value, mask` will pause execution until the values in the `ina` register referenced by the high bits in `mask` are equal to the bits in `value`. In other words, if, for example, `mask=b0100` and `value=b0100`, then the processor will pause until pin 2 is high.[3] Similarly, `waitpne` will wait until the `mask` bits in input register `ina` are *not equal* to those bits `value`.

The `jmp` and `djnz` instructions alter the direction of execution. Normally, the next instruction is executed. At a `jmp #:location`, the next instruction to be executed will be the one labeled `:location`. The instruction `djnz d, #:loop` will decrement the number in `d` and will jump to `:loop` if `d`≠`0`. Otherwise, the instruction next in line will be executed. `tjz` and `tjnz` are similar, but they only `test` the value of `d` without decrementing it.

[3]This is how we generally use `waitpeq`, though we could have multiple pins in mask, and we could have both highs and lows in the values for those pins.

6.3.5 Hub Reads/Writes

The hub has more (but slower) memory than the cogs. You can read and write longs, words, or bytes from and to the hub.

The read instruction `rdlong cogmem, hubmem` will read a long from hub memory address `hubmem` and store that value in the cog location `cogmem`. The `wrlong cogmem, hubmem` instruction will write a long from `cogmem` to `hubmem`. Similarly, `rdword`, `rdbyte`, `wrword`, and `wrbyte` operate on words and bytes.

6.3.6 Locks

Locks (or *semaphores*) are a special utility to allow cogs to negotiate exclusive access to some resource. There are eight lock IDs (0–7) in the Propeller that can be checked out and released. After creating a lock with `locknew lockID`, which stores a lock ID number in `lockID`, you can request a lock with `lockset` and release the lock with `lockclr`.

The way locks work is that a cog has to first create a lock and get its ID. This ID has to be shared with the other cogs. Next, both cogs will request a lock. One (and only one) of the cogs will get it. (The one that asks for it first; because locking is a hub operation, the cogs ask for the lock one after the other in round-robin fashion, so there is no possibility of conflict.) The cog that gets the lock can then, for example, access a shared memory location. The other cogs don't have the lock, so they will simply loop continuously requesting the lock until the cog with the lock releases it.

If a lock is set, then its value is 1; if it is available, then its value is 0.

`lockset lockID wc` sets the value of `lockID` to 1 and returns the *previous* value of the lock (in the `C` flag).

If nobody else had checked out the lock, then its value will be 0; the `lockset` will set the lock to 1 and set `C=0` (because that is its previous value). If somebody else has the lock, then its value will be 1; `lockset` will set `C=1`.

A cog calls `lockset` and then checks the value of `C`. If `C` is `0`, then that cog has the lock; if it is `1`, then it doesn't have the lock.

If a cog does have the lock, it must make sure to eventually call `lockclr lockID`.

6.3.7 Variables

In addition to the instructions (each of which takes up one long), you can declare and initialize variables or reserve blocks of space. Always put the `res` directives at the end of the code.

```
_cVarname long 31415 ' these declare and initialize the vars
_cVarAns  long 42    ' variables are always longs in PASM

_cArry    res 8      ' this reserves 8 longs
```

6.3.8 Special Registers

Each cog has 16 special registers, each of which is a `long` (4 bytes). Because a cog has 512 longs of memory, this leaves 496 longs for instructions and variables.

- `cnt`: The 32-bit system counter is incremented by 1 at every system clock. This register will roll over when it fills up ($2^{32} - 1$ counts, or approximately 4 billion). With an 80MHz clock, that happens every 53 seconds. This is a read-only register.
- `dira`: This register sets the direction for the signals on the pins. The 32 bits of this register correspond to the 32 pins (P0 to P31). If a bit is a 1, then the corresponding pin is an output. *All cogs have their own dira register.* Thus, a pin is an output if *any* cog declares it so; it is an input if *no cog* declares it as an output.

- `outa`: If a pin is set as an output in the `dira` register, then this register can control its value. Setting a bit high (1) in `outa` will set the corresponding pin high. Any cog that has declared a pin as an output can control it. So, it is up to the programmer to avoid conflicts.
- `ina`: The value of each bit in this register reflects the state of the physical pin. If pin PN is high, then bit N of `ina` will be high. Again, this pin will be an input only if no cog has set it as an output.
- `par`: This register is populated by the `cognew` command when the cog is launched. The second argument to `cognew` is (generally) an address in hub memory, and that address is placed in `par` so that the cog can communicate with other cogs.

6.3.9 Counters

I don't discuss the registers `ctra`, `phsa`, and `frqa` in this book, but together they provide a powerful and general-purpose counting capability. You can do a remarkable number of things with these registers, including pulse width measurements, counting the number of pulses, pulse-width modulation (PWM), frequency synthesis and measurement, and much more. See the app note at `https://www.parallax.com/downloads/an001-propeller-p8x23a-counters` for details.

6.4 The Structure of PASM Programs

These programs run from two files: a "driver" file called, for example, `myprog_Demo.spin` (Listing 6-2 shows the outline for such a file) and a worker file called `myprog.spin` (Listing 6-3). The driver file is pure Spin code, but the worker file is a combination of Spin and PASM code. The driver file will have overall control of the program, such as for opening the terminal and starting and stopping cogs. The worker file (or files) will be responsible for a single cog and will generally have a few Spin methods along with the PASM code. At a minimum, it will have the following:

- **INIT:** Set up the needed variables.
- **START:** Start a new cog and load the PASM code into it.
- **STOP:** Stop the cog.

In addition, the worker file will have a section of PASM code that will be loaded into a new cog by the `START` method.

Listing 6-2 shows the driver file `myprog_Demo.spin`.

Listing 6-2. Structure of Spin Driver File

```
{*
 * myprog_Demo.spin : do an important thing
 *}

CON ' Clock mode settings
...
CON ' Pin map
...
CON ' UART ports
...
OBJ
  MYPROG : "myprog" ' load the worker file
VAR
...

PUB MAIN
...
```

```
18  ' initialize and start the worker
19  MYPROG.INIT
20  MYPROG.START
21  ...
22  ' stop the worker
23  MYPROG.STOP
```

- **Line 12:** Read the file `myprog.spin` and make it available as `MYPROG`.
- **Line 19–23:** Call functions `INIT`, `START`, and `STOP` in the library `MYPROG`.

Listing 6-3 shows the worker file `myprog.spin`.

Listing 6-3. Structure of PASM Worker File

```
{*
 * myprog.spin : spin and pasm worker code
 *}
CON
...
VAR
' set up some local variables. At a minimum, keep track of the cog id
byte myprogcogid, mylocalvar

' initialize vars, at a minimum set the cog id to -1 (indicating that no
' cog is running this code)
PUB INIT
  mylocalvar := 0
  myprogcogid := -1

```

```
' start a new cog (after stopping the old one)
' save the cog id as well as returning it
PUB START
  STOP
  myprogcogid := cognew(@MYPROG, @mylocalvar)
  return myprogcogid

' stop the cog - after checking that it is running.
' else do nothing
PUB STOP
  if myprogcogid <> -1
    cogstop(myprogcogid)

' actual PASM code (loaded into new cog by the cognew ↩
command in START)
DAT ' myprog
MYPROG ORG 0
  ' get the address of the variable to be passed here
  mov _cmyvarPtr, par
  ' get the value of that variable
  rdlong _cmyvar, _cmyvarPtr
  ...


' reserve space for the address and value of the variables
_cmyvarPtr res 1
_cmyvar res 1

FIT 496
```

- **Line 8:** These variables are available inside this file to all the functions.
- **Lines 12, 18, 25:** A public function can be called from outside this file (for example, from the driver file, `myprog_Demo.spin`). A public function is written as `PUB INIT`, and a private function (one that can be called only from within this file) is written as `PRI APRIVATEFUNCTION`.
- **Lines 12–14:** The `INIT` function that initializes variables.
- **Lines 18–121:** The `START` function first stops the new cog (if it is running) and then starts it. The `cognew` command takes two arguments: the address of the PASM code and the address of a local variable, which is passed to the PASM cog. The function returns the number of the newly launched cog.
- **Lines 30–43:** The PASM code that is copied to a new cog and run.
- **Line 30–31:** The special operator `DAT` announces the start of the PASM code. The line `MYPROG ORG 0` assigns a name (`MYPROG`) to that code and says that it starts at address 0 in the cog. (This is always the case in this book, though it doesn't have to be; code could start anywhere within the 496 longs of the cog, but that is advanced voodoo!)
- **Lines 33–41:** These lines are the way parameters get passed to the code. You'll learn more about that in the next sections.
- **Line 43:** This line always ends the PASM code.

6.5 Passing Parameters to PASM

A significant challenge in PASM programming is exchanging data between cogs and between Spin and PASM cogs. There are two main ways this is done.

- An address in hub memory is passed to a cog when it is launched. The instruction `cognew(@PROG, @var)` will place the address of `var` into the special register `PAR` when the PASM cog `PROG` is run.
- An address in hub memory is placed into cog memory before the cog is launched.

This is discussed at length in Sections 8.3 and 8.4.

6.6 Summary

PASM instructions have four parts: the instruction itself (`mov, add,...`), the destination, the source, and an optional *effect* (`wc` or `wz`) that sets the value of the `C` and `Z` flags.

To communicate between cogs, both cogs must have the address of a variable that they regularly check. That address is passed to a new cog on launch in the `PAR` register.

```
VAR
  'variable1 and variable2 are stored in successive locations
  long variable1, variable2

PUB MAIN
  ' cognew command will store the address of variable1
  ' in PAR and then launch MYCOG in a new cog
  cognew(@MYCOG, @variable1)

```

```
DAT
MYCOG org 0
  mov _cvar1Ptr, par ' when mycog is launched, ↵
                     ' par contains the ↵
                     ' address of variable1
  mov _cvar2Ptr, par ' the next long location contains the ↵
                       address
  add _cvar2Ptr, #4 ' of variable2

  rdlong _cvar1, _cvar1Ptr ' the actual value of variable1
  ' is obtained by a rdlong
  rdlong _cvar2, _cvar2Ptr
```

CHAPTER 7

Interacting with the World

One of the main uses of a Propeller is to “talk” to hardware such as motors, relays, switches, LEDs, and so on. In the Propeller there are 32 general-purpose input/output pins, P0–P31. Figure 7-1 shows an overview of the relationship between the cogs and pins. Pins P30 and P31 are usually reserved for the programming and serial ports. Pins P28 and P29 are usually tied to an electrically erasable programmable read-only memory (EEPROM) that stores the program even when there is no power applied. So, pins P0–P27 are available for general input/output use.

Again, I must emphasize that all the cogs can run in parallel, so they can interact with the pins at the same time. If a cog has declared a pin an input, then it can read the value of that pin *at the same time as other cogs do*. If a pin is declared an output by more than one cog, then the output of that pin is the logical OR of the output of those cogs.

Three registers control these pins.

- `DIRA` is a 32-bit register that controls the direction of the pin associated with each bit. If bit N of this register is 1, then the corresponding pin `P<N>` will be an output, and if it is zero, that pin will be an input.

- `OUTA` is a 32-bit register that sets the value of a pin `P<N>` by setting or clearing the associated bit N. These pins will be affected only if the value of the associated `DIRA` bit is set to output (1).
- `INA` is a 32-bit register that reflects the value of the signal on pin `P<N>`. A low voltage (0–0.7V) is a zero on the associated bit N of the register, and a high voltage (2.7–3.3V) is a 1. Again, `bitN` of `DIRA` should be set to input (0).

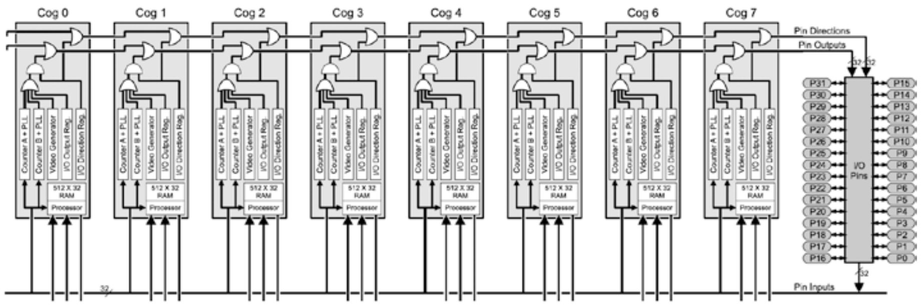


Figure 7-1. *Block diagram of the Propeller showing the cogs and pins*

All eight cogs have access to all of the pins. Each of the cogs has its own independent `DIRA`, `INA`, and `OUTA` registers. The output of a pin is what is "agreed on" by all the cogs. If more than one cog declares a pin as output, then the pin will be high if *any of those* cogs sets it high. The pin will be low if *all of those* cogs set it low. In Figure 7-2, a switchman is manually operating a switch that controls which track a train will take.

Figure 7-2. *Switchman throwing a switch at the Chicago and NW Railroad Proviso yard, Chicago, IL, 1942. Photo by Jack Delano; available at the Library of Congress Farm Security Administration archives.* `www.loc.gov/pictures/item/fsa1992000705/PP/`.

A pin will be an input if *no active cog has it as an output.*

To view the result of setting a pin, a logic analyzer is useful. A logic analyzer attaches to a pin and displays the *logical* state of the pin as a function of time (1 or 0). Unlike an oscilloscope, you can monitor multiple pins (usually 8 or 16), and importantly, the logic analyzer software is aware of common protocols such as Universal Serial Receive/Transmit (UART), Serial Peripheral Interface (SPI), Inter-Integrated Communication (I2C), and so on. (I am partial to the Logic8 from Saleae.[1]) See also the Papilio Logic Analyzer.[2]

[1]`https://www.saleae.com`

[2]`http://store.gadgetfactory.net/papilio-fpga-logic-analyzer-kit/`

7.1 Outline

In this chapter we will read and set the value of pins in both Spin and PASM. We will look at the SPI communication protocol (a common method for communicating between embedded devices). We will implement SPI between cogs as a way to log data from a PASM cog to the main Spin code. Finally, I introduce the concept of *semaphores* or *locks* that allow two cogs to interact without confusion or conflict. This is a dense chapter, so feel free to refer to it if and when you need it!

7.2 Timing in Spin and PASM

Instructions in Spin run slowly compared to the same instruction in PASM (by an order of magnitude or more). In addition, in Spin, the amount of time an instruction takes to complete is subject to change. By contrast, the timing of PASM instructions is short (generally four clock cycles) and unvarying. For applications that require precise and rapid timing (high-frequency clocks or monitoring a high data rate line), PASM is preferred. Each PASM instruction has a known number of clock cycles to complete.

```
CON ' Clock mode settings
  _CLKMODE = XTAL1 + PLL16X
  _XINFREQ = 5_000_000

  ' system freq as a constant
  FULL_SPEED = ((_clkmode - xtal1) >> 6) * _xinfreq
  ' ticks in 1ms
  ONE_MS = FULL_SPEED / 1_000
  ' ticks in 1us
  ONE_US = FULL_SPEED / 1_000_000
```

- **Lines 2–3**: These define the clock speed of the Propeller. `_XINFREQ` is the frequency of the crystal oscillator. `_CLKMODE` is a register that sets the `CLK` register to (in this case) generate a clock that is 16 times the oscillator frequency.
- **Line 6**: Here we define a constant for the number of clock ticks in one second. It is somewhat cryptic, but in short, `XTAL1` and `PLL16X` are predefined constants. The expression `_CLKMODE - XTAL1 = PLL16X = 0x40_00`.

Therefore, `PLL16X >> 6 = 16` (right shift by 6 bits). Finally, multiply that by the oscillator frequency. This is a reliable way to get the *startup* clock speed.

7.3 Spin

In Spin these registers are usually set as shown in Listing 7-1.

Listing 7-1. Toggle a Pin in Spin (ch7/io0.spin)

```
CON
  BLUE = 10 ' blue led

PUB MAIN
  DIRA~ ' set all pins low (no output)
  OUTA[BLUE] := 0 ' set pin 10 low
  DIRA[BLUE] := 1 ' set pin 10 to output
  repeat
    ! OUTA[BLUE] ' toggle pin 10
    PAUSE_MS(1000)
```

- **Line 5**: The tilde (~) *after* a variable says to set that variable to zero.
- **Line 7**: When the array form of addressing (`arr[j]`) is used with a register (`DIRA[BLUE]`), the effect is to address individual bits. In this case, only bit 10 of `DIRA` is set to 1, so `P10` is set to output.
- **Line 9**: The exclamation mark (`!`) is a bitwise negation of the bit `OUTA[BLUE]`, which will toggle pin P10.
- If we wish to read the value on a line, the Spin code is shown in Listing 7-2:

Listing 7-2. Read a Switch and Pin (ch7/io1.spin)

```
 1  CON
 2    SW = 11 ' normally open, high
 3    SWMASK = |< SW ' set pin <SW> high
 4    INPIN = 12
 5
 6  PUB MAIN | val
 7    DIRA~ ' set all pins low (no output)
 8
 9    ' initially wait until switch is open (high)
10    waitpeq(SWMASK, SWMASK, 0) ' wait until high
11    repeat
12      waitpne(SWMASK, SWMASK, 0) ' wait for it to go low
13      val := INA[INPIN]
14      waitpeq(SWMASK, SWMASK, 0) ' wait for release of switch
```

- **Line 3**: Set bit 11 of `SWMASK` high. The operator `|<` is referred to as a “Decode” operator that sets the bit corresponding to the number in `SW`.

- **Line 10**: `SWMASK` is used in two ways here: `waitpeq(`*`Value`*`, `*`Mask`*`, 0)`. The first argument to `waitpeq` (*`Value`*) is the value that the Propeller will compare against the values of the input pins that are set in the *`Mask`* argument. In other words, bit 11 is 1 in *`Value`*; bit 11 is 1 in *`Mask`*. Compare the value 1 to bit 11 of `INA`, and wait until they are equal, that is, until `P11` is high.
- **Line 12**: Similar to `waitpeq`, `waitpne` waits until the *`Value`* argument is *not equal* to the pins set in *`Mask`*. Bit 11 of *`Value`* is 1, so wait until `P11` is *not* 1.
- **Line 13**: To read the value of a line, simply read the value of a bit of the `INA` register.

7.4 PASM

In PASM the same registers (`DIRA`, `OUTA`, and `INA`) are available at the addresses (unsurprisingly) `dira`, `outa`, and `ina`. These addresses are registers in the reserved part of the cog. Recall that when a cog is launched, 512 longs are copied to the cog RAM, of which the last 16 longs are reserved registers (including our old friend `par`).

7.4.1 Toggle a Pin in PASM

Similar to the Spin code in Listing 7-1, we toggle the value of a pin once a second but using PASM, as shown in Listing 7-3.

Listing 7-3. Toggle a Pin in PASM (ch7/io2-pasm.spin)

```
...
' << ADD THESE LINES
CON
```

```
  BLUE = 10
  SW = 11
  INPIN = 12
  ONESEC = ((_clkmode - xtal1) >> 6) * _xinfreq

VAR
  ...
  byte rdpinCogId ' << ADD THIS

PUB MAIN
  ...
  ' << ADD THESE LINES
  rdpinCogId := cognew (@RDPIN, 0)
  UARTS.STR(DEBUG, string (" rdpinCogId : "))
  UARTS.DEC(DEBUG, rdpinCogId)
  UARTS.PUTC(DEBUG, CR)
  UARTS.PUTC(DEBUG, LF)

' << ADD THESE LINES
DAT ' RDPIN

RDPIN ORG 0
  mov dira, #0 wz ' set all pins to input
  muxnz outa, _cblueMask ' set pin low
  muxz dira, _cblueMask ' set led pin to output

  mov r0, cnt
  add r0, _coneSec
:loop
  waitcnt r0, _coneSec
  xor outa, _cblueMask
```

```
35    jmp #:loop
36
37  _cblueMask long |< BLUE
38  _cswMask long |<SW
39  _coneSec long ONESEC
40  r0 res 1
41  FIT 496
42
43  ' Program ends here
```

- **Line 26**: Set all pins to input. The `wz` effect will set Z.
- **Line 27–28**: Set pin `BLUE` (10) low before setting it to be an output. The `muxnz outa, _cblueMask` instruction says to set the pins in `outa` that are referenced in `_cblueMask` to the value of `NOT Z` (`outa[_cblueMask] := !Z`. In other words, pin 10 is set in `_cblueMask`, so set pin 10 of `outa` to `!Z`, which is 0. `muxz` sets `dira[_cblueMask] := Z`, which sets pin 10 to be an output.
- **Lines 30–33**: Set `r0` to the current counter value plus one second worth of counts. Wait until the counter reaches that value (`waitcnt` will increment `r0` by `_coneSec` when it expires so it is ready for the next `waitcnt`).
- **Line 34**: Toggle the output pin 10. `xor outa, _cblueMask` is the bitwise exclusive OR of the value of the output pins and the mask register (which has pin 10 set high). The result is written back to `outa`. So, if `outa[10] == 1`, then 1 XOR 1 = 0, and `outa[10]` is set to zero. If `outa[10] == 0`, then 0 XOR 1 = 1, and `outa[[10]` is set to one.

7.4.2 Monitor a Switch

As in Listing 7-2, we monitor a switch and then read the value of a pin when the switch closes, as shown in Listing 7-4.

Listing 7-4. Read a Pin in PASM (ch7/io2-pasm.spin)

```
CON
  BLUE = 10
  SW = 11
  INPIN = 12
  ONESEC = ((_clkmode - xtal1) >> 6) * _xinfreq

DAT
STEIM ORG 0

  mov dira, #0 wz ' set all pins to input
  waitpeq _cswMask, _cswMask
:loop
  waitpne _cswMask, _cswMask
  test _cinMask, ina wc
  rcl _cval, #1
  waitpeq _cswMask, _cswMask
  jmp #:loop

_cblueMask long |< BLUE
_cswMask long |<SW
_cinMask long |< INPIN
_coneSec long ONESEC
r0 res 1
```

- **Line 11**: As in the Spin code, `waitpeq Value, Mask` waits until the pins in `INA` that are referenced in `Mask` are equal to `Value`."
- **Line 13**: `waitpne` waits until `Mask` is *not equal* to the value.
- **Lines 14–15**: To read a pin, `test _cinMask, ina wc` will set `C` flag to the bitwise AND of the mask and the `ina` register. `rcl _cval, #1` will move the `C` flag into the low bit of `_cval`.

7.5 Communication Protocols

There are number of common ways to send data from one device to another on a small number of lines, including UART, I2C, and the 1-Wire protocols. These are commonly classed as *serial* communication channels because the bits are transmitted over time. In contrast, a *parallel* channel would use a number of lines to send the bits at the same time. In Figure 7-3, an early serial communication device is shown: an electric telegraph which would visually display the signal transmitted from the other end.

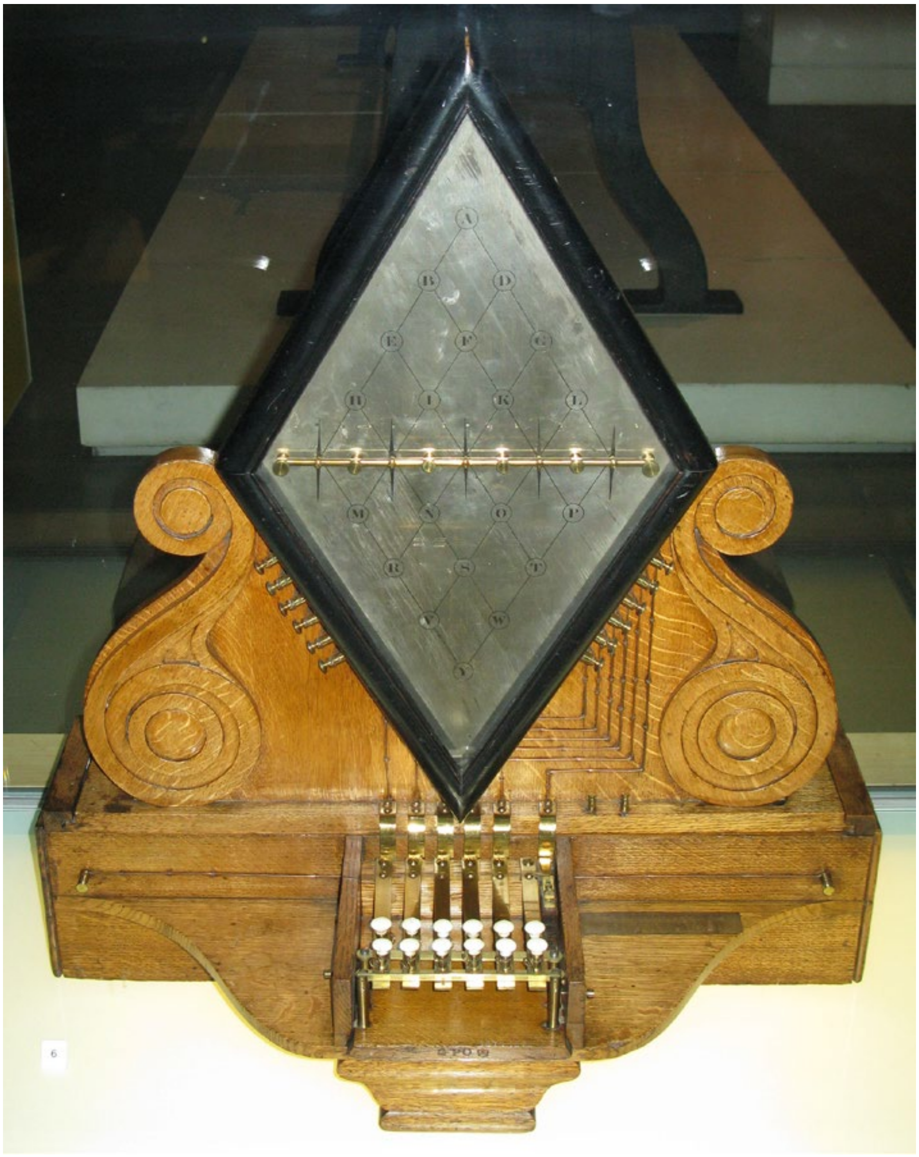


Figure 7-3. *Five-needle electric telegraph invented by Charles Wheatstone (of the Wheatstone bridge), 1837. The telegraph was used to signal when trains arrived and left stations. Now at the London Science Museum. Photo by Wikipedia user* `Geni`*; license CC-BY-SA GFDL.*

A widely used serial protocol for interdevice communications is the SPI bus. The SPI protocol requires four lines for bidirectional communications between a so-called master and multiple slave devices. The SPI protocol uses a bitwise data transmission mechanism, with a bit sent by both sides (and that bit received by the other side) at each SPI clock cycle. The SPI clock frequency is typically a few hundred kilohertz to a few megahertz. Here we will use an 8kHz clock.

SPI communications are bidirectional, but one of the two ends is designated the *master,* and the other is the *slave*. The master will control the timing of the transfer by generating the select signal and the SPI clock, and the slave will read from the master.

The slave will also write to the master at the same time. Therefore, the master cannot set a pace that is too fast for the slave to keep up with.

SPI is fundamentally quite simple (though the devil is in the details). To send a number from master to slave, the master indicates the beginning of the transfer by pulling the select line low. It then toggles a clock and makes sure that each successive bit of the number is ready on the active edge of the clock (generally the rising edge). After the bits are all sent, the master pulls the select line high. At the other end, the slave waits until the select line is low. It then watches the clock line and receives a bit at each active edge. The end of the transfer is signaled by the select line going high.

- **Select**: The select or chip select (`CS`) line (active low) selects the slave devices with which the master wants to communicate and determines the start and end of communications. The master device generates this signal.
- **Clock**: The SPI clock line (SCLK) controls the timing of data transmission. The most common arrangement is for the rising edge of the clock to be the one at which data is exchanged and the falling edge is when the two sides are free to change the data on that line. The master device generates the clock.

- **Data out**: The data out or master out or master out/slave in (`MOSI`) line is where the data from the master to the slave is placed. The master device will ensure that a data bit is stable on the line prior to the rising edge of the clock. This is because on the rising edge, the slave device reads the value. The master should keep the data on this line stable until the falling edge because the slave could read it at any time between the rising and falling edges.
- **Data in**: The data in or master in or master in/slave out (MISO) line is where data from the slave to the master is placed. The master will read the MISO line on the rising edge of SCLK. Thus, at each rising edge of SCLK, a bit is sent from master to slave and from slave to master.

The interpretation of the bits (whether big- or little-endian, number of bits, and so on) is entirely up to agreement between the slave and the master. Figure 7-4 shows the case where we have 8 bits. The red lines are the *active edges* at which the `MOSI` line is read by the slave. The blue lines are when the master can change the value of the `MOSI` line in preparation for the next active edge.

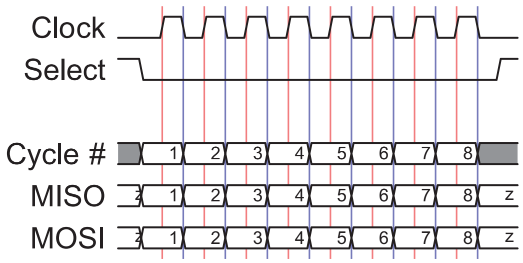


Figure 7-4. *SPI timing diagram for the case when the clock starts out low (CPOL=0) and the data is required to be valid on a rising edge (CPHA=0)*

7.6 SPI Logging

The values on the pins can be set by any cog and read by any cog. That means we can use them to communicate *between cogs*. We will use that as a logging facility where the PASM cog will write to the SPI bus and the Spin cog will read from it. As the Spin cog is slower, it must control the transactions. In other words, the PASM cog is the master, and the Spin cog is the slave.

We are going to write an SPI logging utility. The Spin cog (main) will request a log value, and a PASM cog (`logtst`) will transmit the log value. The main cog will read that value and print it out. The handshaking between the cogs is as follows:

- The PASM cog will block, waiting for the `REQ` line to be asserted (set to the active level, in this case raised).
- When the main cog (the slave) is ready to receive a log value, it will raise the `REQ` line.
- This will signal the PASM cog (the master) to initiate an SPI transfer by lowering the `CS` line (the `CS` line is active low, so it is *asserted* by lowering it).
- The falling `CS` line will signal the main cog to lower the `REQ` line so that no further SPI transfers start until the main cog has finished with the current one and has successfully printed the value.

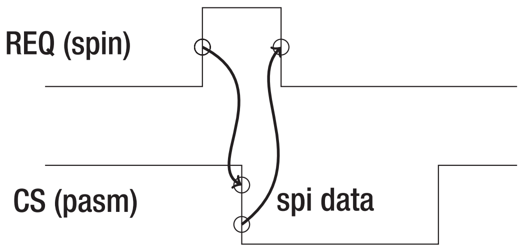


Figure 7-5 shows the output of a logic analyzer (LA). The LA can monitor and trigger on individual lines (here I triggered on `REQ` on channel 0). In addition, logic analyzers can interpret well-known communication protocols such as the RS-232 serial protocol, the I2C protocol, and, as in this case, the SPI protocol. I have informed the LA of the four SPI lines, the endianness and length of the data, and the phase and polarity of the clock; the LA can interpret the data on the `MOSI` and MISO lines and display the result. In this example, the `MOSI` line is showing a 32-bit number that was transmitted MSB first and is interpreted as `0x2A`.

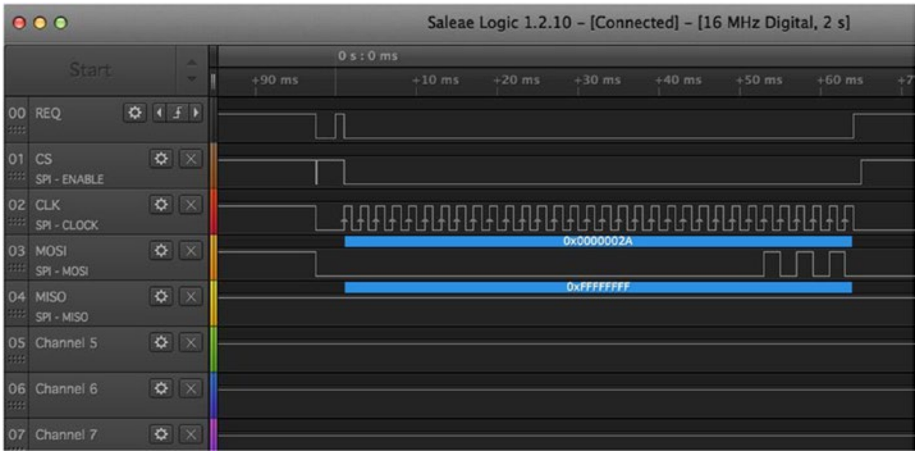


Figure 7-5. *Logic analyzer display*

In the Spin code (Listing 7-5), we define the pins, start the `spitst` cog, and assert the `REQ` line. When the `CS` line is asserted by the PASM cog, we read the log value and then re-assert the `REQ` line.

Listing 7-5. SPI Logging, Spin Side (ch7/spi-log Demo.spin)

```
...
CON
  REQ = 0
  CS = 1
  CLK = 2
  MOSI = 3
  MISO = 4

  CSMASK = |<CS
  CLKMASK = |<CLK
VAR
  byte logCogId

...

PUB MAIN | x, x0, logVal
...
  logCogId := -1

  ' set the REQ line low, then set it as an output line
  ' all others are inputs
  outa[REQ] := 0
  dira ~ ' all lines in
  dira[REQ] := 1 ' req out

  SPILOG.INIT
  logCogId := SPILOG.START
  UARTS.STR(DEBUG, string(CR, LF, " logCogId : "))
  UARTS.DEC(DEBUG, logCogId)
  UARTS.PUTC(DEBUG, CR)
  UARTS.PUTC(DEBUG, LF)

  ' wait here until PASM cog sets CS line high
  waitpeq(CSMASK, CSMASK, 0)

  ' OK ready for SPI
  outa[REQ] := 1 ' assert req
```

```
38    repeat
39      ' wait for cs mask to go low
40      waitpne(CSMASK, CSMASK, 0)
41      !outa[REQ] ' lower req
42      logVal := READ_SPILOG 'read 32 bits
43      UARTS.HEX(DEBUG, logVal, 8) ' print out logVal
44      UARTS.PUTC(DEBUG, CR)
45      UARTS.PUTC(DEBUG, LF)
46      !outa[REQ] ' raise req and loop
```

- **Lines 3–7**: Define pins.
- **Lines 22–24**: Set all pins to input for main cog, except for REQ.
- **Lines 26–27**: Launch the SPILOG PASM cog.
- **Line 34**: Make sure CS is high (that is, not currently in an SPI transfer). Assert REQ.
- **Lines 40–46**: Wait until the CS line is lowered by the PASM cog, immediately de-assert the REQ line, read a log value, and print it. Raise the REQ line to signal that the main cog is ready for another log value. Repeat.

The actual SPI read is done with the method shown in Listing 7-6.

Listing 7-6. Method to Read 32 Bits from SPI

```
PUB READ_SPILOG : logVal | b
  logVal := 0
  repeat 32
    waitpeq(CLKMASK, CLKMASK, 0)
    b := INA[MOSI]
    waitpne(CLKMASK, CLKMASK, 0)
    logVal <<= 1
    logVal |= b
```

The actual SPI read is straightforward; it waits for the clock line to go high (`waitpeq`), reads a bit (`b := INA[MOSI]`), and shifts it into `logVal`, as follows:

```
1  logVal <<= 1
2  logVal |= b
```

- **Line 1**: Shift the bits in `logVal` left by one position.
- **Line 2**: `b` is the value read earlier (either 0 or 1). By `OR`-ing it with `logVal`, we set the lowest bit to the value of `b`.

The `waitpne` instruction is there so that we wait until the clock line goes low before looping so that we don't read the same bit twice.

7.6.1 PASM SPI Write

The core of the PASM SPI write is shown in Listing 7-7 and the code following the listing, with two subroutines that set the pins and do the actual writing.

Listing 7-7. SPI Logging, PASM Side (ch7/spi-log.spin)

```
1  DAT 'spilog
2  SPILOG  ORG 0
3
4    call #SETUP_PINS
5
6    mov _clogVal, #42
7    call #WRITE_SPI
8    ...
```

- **Line 4**: Set up the `REQ` pin as input and the SPI pins as outputs.

- **Lines 6–7**: Place the log value to be transmitted into `_clogVal` and call `WRITE_SPI` to transmit. `WRITE_SPI` will wait for `REQ` to be raised and will then transmit `_clogVal` on the SPI lines.

The subroutine to set the pins (SETUP_PINS) is shown in Listing 7-8.

Listing 7-8. Subroutine to set the SPI pins' direction

```
 1  SETUP_PINS
 2    mov dira, #0, wz
 3
 4    muxz outa, _ccsMask 'preset cs high, and then to output
 5    muxz dira, _ccsMask
 6    muxnz outa, _cclkMask ' preset clk low
 7    muxz dira, _cclkMask
 8    muxnz outa, _cmosiMask ' preset mosi low
 9    muxz dira, _cmosiMask
10  SETUP_PINS_ret ret
```

- **Line 2**: Set all pins to inputs.
- **Lines 4–5**: Set `CS` high and then set `CS` to output.
- **Lines 6–9**: Set `CLK` and `MOSI` low and then set them to output.

In Listing 7-9, we do the actual work of writing 32 bits to the `MOSI` line. First we wait for the REQ line to be asserted, then we loop 32 times, setting the `MOSI` line appropriately (with a short wait between bits).

Listing 7-9. Subroutine to transmit the data on MOSI

```
1  WRITE_SPI
2    waitpeq _creqMask, _creqMask
3    mov r0, #32 wz ' Z is set = 0
```

```
  mov _cdt, cnt
  add _cdt, _cEighthMS
  waitcnt _cdt, _cEighthMS

  ' lower cs
  xor outa, _ccsMask

  ' tx 32 bits, msb first
:spiloop
  rol _clogVal, #1 wc ' set C from high bit of logVal
  muxc outa, _cmosiMask ' set mosi to C

  muxnz outa, _cclkMask ' raise clock (Z=0 from above)
  waitcnt _cdt, _cEighthMS
  xor outa, _cclkMask ' lower clock
  waitcnt _cdt, _cEighthMS
  djnz r0, #:spiloop

  ' raise cs
  xor outa, _ccsMask
WRITE_SPI_ret ret
...
_cdt long 0
_cOneSec long ONE_SEC
_cOneMS long ONE_MS
_cOneUS long ONE_US
_cEighthMS long ONE_MS >> 3

_creqMask long |<REQ
_ccsMask long |<CS
_cclkMask long |<CLK
_cmosiMask long |< MOSI
```

- **Line 13**: Set the loop index and set `Z` to zero.
- **Lines 14–16**: `Set_cdt` to the current counter, add 1/8ms (125us), and wait until then. `waitcnt` takes two arguments, and the counter will wait until it is equal to the first argument. It will then add the second argument to the first so that you can call `waitcnt` again.
- **Line 19**: Lower `CS`. `xor outa, _ccsMask` will toggle the `CS`.
- **Line 23–24**: Get the bits, with the most significant bit first, and place it on the `MOSI` line. The `rol _clogVal, #1 wc` instruction will rotate left and put the highest bit in `C`. The instruction `muxc outa`, `_cmosiMask` will set `MOSI` to `C`.
- **Lines 26–29**: Raise the clock line, wait 1/8th of a millisecond, lower the clock, wait again, and loop.
- **Line 33**: Lower the `CS`.

7.6.2 Logging Deadlock

Warning! If you call `WRITE_SPI`, you must have another cog that raises the `REQ` line; otherwise, you will block forever.

At any time you can call `WRITE_SPI` in the PASM code. It will block until the Spin code raises the `REQ` line. At that point, the PASM code will transmit the log value and continue.

7.7 Locks

On single-track lines, railroads needed a foolproof way to prevent two trains from traveling on the same section of track at the same time. They settled on a simple but elegant solution: the semaphore. A brass cylinder or token is cast and engraved with the name of the stations at each end of the section of single-track. A train could enter that section *if and only if* the engineer had physical possession of the token. When he arrived at the station at the far end, he would give the token to the station master, who could pass it on to a train traveling in the other direction.

You still see a version of this when road crews are working on potholes and signals at each end control the traffic.

7.7.1 Introduction to Locks

The propeller has semaphores for the same reason: to control access to *critical shared resources*. To prevent a collision (for example, one cog is modifying an array at the same time that another is reading from it), the propeller has eight semaphores. In Figure 7-6, we see a semaphore that controlled the movement of trains in order to prevent collisions.

- `locknew/lockret`: Create or destroy a semaphore.
- `lockset`: Request the semaphore. If it is free (semaphore = 0), set the state of the semaphore to 1 and return a 0 (obtaining the lock). If it isn't free (semaphore = 1), return a 1 (*not* obtaining the lock). You must check the return value to know whether you obtained the lock or not.
- `lockclr`: Set the state of the semaphore to 0, releasing the semaphore.

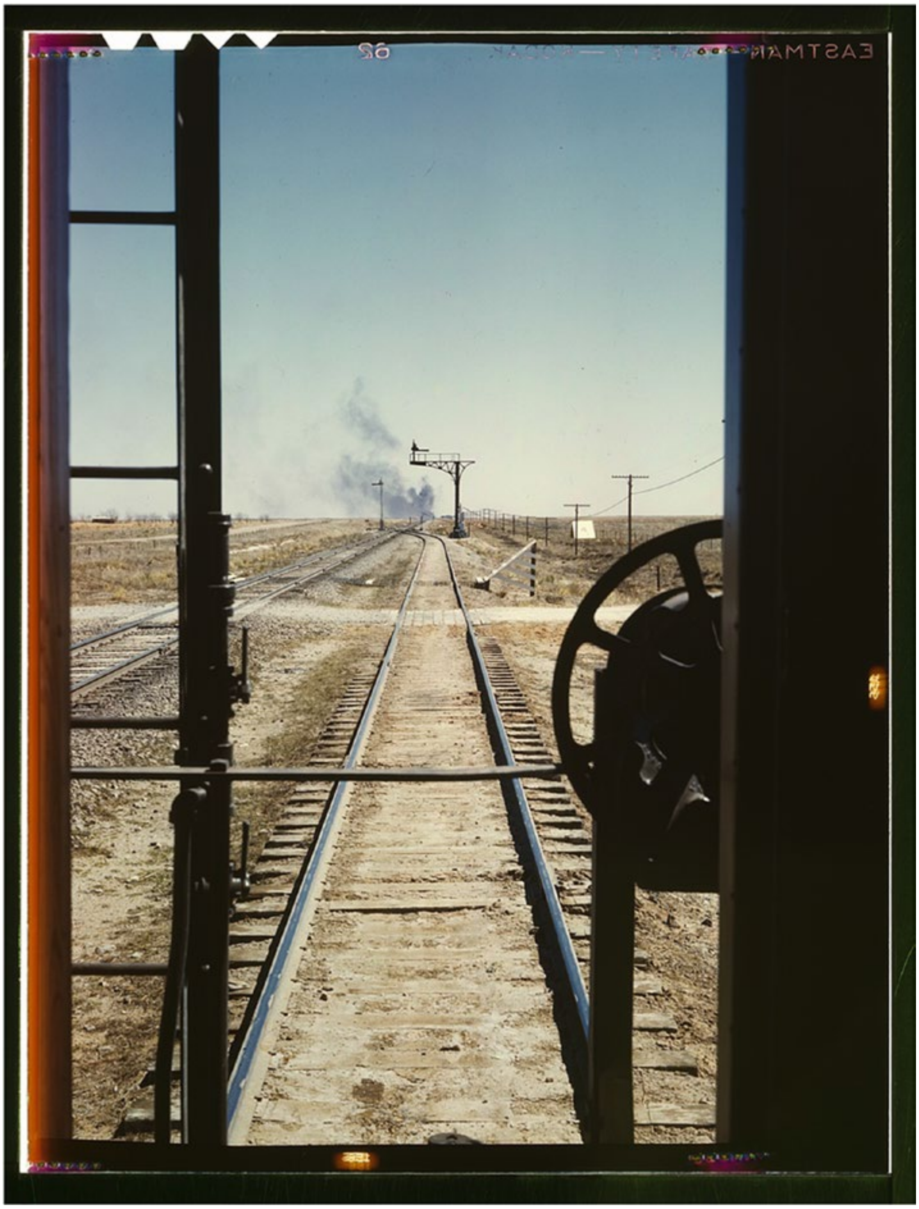


Figure 7-6. *Waiting for the signal, Santa Fe RR Train, Melrose, NM. Photo by Jack Delano, 1943. From the Library of Congress Farm Security Administration archives.* `http://www.loc.gov/pictures/item/fsa1992000785/PP/`.

Here is a sketch of the process, with time proceeding to the right. ("Time" is a bit of misnomer here; because locking is a hub operation, even though both cogs may request the lock at the same time, the hub will service those requests in order.) At time 1, cog 0 acquires the lock. Because `lockset` is a hub operation, only one cog a time can request the lock. Though it looks like both cogs are competing for the lock, in fact only of them can obtain it. In this case, cog 0 received the lock, and when cog 1 requested it (one clock cycle later), it was informed that somebody else had the lock (because `lockset` returns 1). Remember, the propeller operates in round-robin fashion for hub operations, providing exclusive access to the hub for one cog, then the next, and so on.

At time 2, cog 1 again requests the semaphore, and the Propeller again returns the *previous* state of the lock, 1, which indicates that somebody else has it. This continues until time 5, when cog 0 releases the semaphore, and it is set to 0. At time 6, cog 1 again requests the lock, and this time the *previous* value is 0, so cog 1 knows that it has the semaphore.[3] It holds it until time 9.

cog0	set				clr				
$\boxed{0}$	$\boxed{1}$	$\boxed{1}$	$\boxed{1}$	$\boxed{1}$	$\boxed{0}$	$\boxed{1}$	$\boxed{1}$	$\boxed{1}$	$\boxed{0}$
cog1	set	set	set	set	set	set			clr
0	1	2	3	4	5	6	7	8	9

The semaphore is created, and then a `lockset/lockclr` pair of instructions brackets the critical section of code. So, for example, in our code, cog 0 could acquire samples between times 1 and 5, but we must prevent cog 1 from attempting to compress them during that time. Between times 6 and 9 the compression can safely proceed.

[3] I lie. In reality, cog 0 would have released the cog at time 5, and during the next clock cycle, cog 1 would have requested and received the lock, but for illustration purposes, I fibbed.

The way we have written the code, there is in fact no chance of a collision between sample acquisition and compression. The main cog *blocks* while the compression cog is working, so it is impossible for it to modify `sampsBuf`. However, that isn't very good design. It is wasteful for `main` to sit there twiddling her thumbs while `steim` is off doing his job. She could be (and usually is) performing other tasks. It is under that type of system design that the semaphore is most useful. After all, if one has a multicore parallel machine, we might as well use it as a…multicore…parallel…machine!

7.7.2 Using Locks for Logging

We could, for example, use a semaphore to signal between cogs. If you don't want to waste an I/O line for the `REQ` signal between cogs for logging, you could use a semaphore instead, as shown here in Listing 7-10:

Listing 7-10. Demonstration of using locks for SPI signalling

```
PUB MAIN

...
  logSem := locknew
  repeat until not lockset(logSem) 'acquire semaphore
  COMPR.START ' start the pasm cog
...

  lockclr(logSem) ' release the semaphore, allowing PASM access
  repeat
    waitpne(CSMASK, CSMASK, 0)
    logVal := READ_SPILOG
```

```
13      waitpeq(CSMASK, CSMASK, 0)
14      repeat until not lockset(logSem)  ' re - acquire ↩
        semaphore
15      UARTS.STR(DEBUG, string(" Log value : "))
16      UARTS.HEX(DEBUG, logVal, 8)
17      UARTS.PUTC(DEBUG, CR)            ' release semaphore
18      lockclr(logSem)
```

- **Lines 4–9**: Create a new semaphore, acquire it, and start the PASM cog. When ready to start logging, release it.
- **Lines 11–13**: Read a log value on the SPI lines.
- **Line 14**: `lockset` will return `TRUE` if somebody else has the token. In that case, `repeat until` won't exit. Eventually, the other person will release the semaphore, `lockset` will return `FALSE`, `repeat until` will terminate, and control will continue.
- **Lines 15–18**: We now have the token and can slowly print out the log value, *confident that the PASM cog won't try to send another value*.
- **Line 18**: Release the semaphore so that the PASM cog can acquire it when it is ready to send another log value.

This is the code in the Spin section that interfaces with the locks (Listing 7-11).

Listing 7-11. Spin code that uses locks to signal SPI communications

```
' in the pasm cog, we must somehow pass the semaphore ↩
number (logSem)
' to the cog: _clogSem
...
```

```
 4
 5  WRITE_SPI
 6  :semLoop                  ' acquire semaphore
 7    lockset _clogSem wc
 8    if_c jmp #:semLoop
 9
10    ' <<WRITE LOG VALUE TO SPI >>
11    lockclr _clogSem       ' release semaphore
```

- **Lines 6–8**: In the `PASM` cog, the `WRITE_SPI` function will check whether the semaphore is free. If so, it will acquire it, *confident that the Spin cog is ready*.

  This loop will repeat as long as somebody else has the token. When nobody else has the token, `C`=0, and we continue to transmit the log value on the SPI lines.

- **Line 8**: Once we are done, release the semaphore.

7.8 Some Common Tasks

Here are some examples of common operations, with both Spin and PASM equivalents shown. As can be seen, some things are much simpler in Spin. This must be weighed against the speedup that can be achieved with PASM.

7.8.1 Assignment

Spin	PASM
`x := 42`	`mov _cX, #42`
`y := 31415926`	`mov  _cY,  _cbigNum`
	`_cbigNum long 31415926`

7.8.2 Multiplication

Spin	PASM
`z := x * y`	`shl _cX, #16`
	`mov r0, #16`
	`shr _cY, #1 wc`
	`:loop`
	`if_c add _cY, _cX wc`
	`rcr _cY, #1 wc`
	`djnz r0, #:loop`

The multiply code is from Appendix B of the Propeller manual. Two 16-bit numbers, _cX[0..15] and _cY[0..15] are multiplied, and the result is saved to _cY.

Let $x = 42$ and $y = 2$. Here are their binary representations:

	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
x:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	
y:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	C

After `shl _cX, #16`, here is what they look like:

x':	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
y:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	C

After `shr _cY, #1 wc`, here they are again:

x':	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
y:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Loop 1 of 16

Because `C`=0, the add is not performed.

After `rcr _cY, #1 wc`, here is what they look like:

x':	0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
y:	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	1

Loop 2 of 16

Because `C`=1, the add is performed. The add has a `wc` effect, which will set `C` if the add overflows. In this case, `C`=0.

Here they are after the add:

x':	0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
y:	0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0

Here is the *y* register after `rcr` (the *x*' register is unchanged):

y:	0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0

From here on, *y* is shifted right once each iteration of the loop. No more adds are performed as all the remaining bits of *y* (bits 0–13) are 0.

Loop 16 of 16

The final result is $y = 42 \times 2 = 84$.

x':	0 0 0 0 0 0 0 0 0 0 1 0 1 0 1 0	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
y:	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0 0 0 0 0 0 0 0 0 1 0 1 0 1 0 0	0

7.8.3 Division

Spin	PASM

`q := x / y`
`'quotient (32 bit)`
`r := x // y`
`'remainder (32 bit)`
	`' Divide x [31..0] by y [15..0]`
	`' (y [16] must be 0)`
	`' on exit, quotient is in x [15..0]`
	`' and remainder is in x [31..16]`
	`' get divisor into y [30..15]`
	`shl _cY, #15`
	`' ready for 16 quotient bits`
	`mov r0, #16`
	`:loop`
	`' y =< x? Subtract it,`
	`' quotient bit in c`
	`cmpsub _cX, _cY wc`
	`' rotate c into quotient,`
	`' shift dividend`
	`rcl _cX, #1`
	`' loop until done`
	`djnz r0, #:loop`
	`' quotient in x [15..0],`
	`' remainder in x [31..16]`

This is also from the appendix. Get a pad of graph paper and confirm for yourself how it works.

7.8.4 Loops

Spin

```
x0 := 0
x := 1
repeat 8
  f := x + x0
  x0 := x
  x := f
```

PASM

```
   mov _cx0, #0
   mov _cx1, #1
   mov _cf, _cx1

   mov r0, #8
 :loop
   add _cf, _cx0
   mov _cx0, _cx1
   mov _cx1, _cf

   mov _clogVal, _cf
   call # WRITE_SPI
   djnz r0, #:loop
```

The critical parts are `mov r0, #8`, which sets the loop counter and `djnz r0`, and `#:loop`, which decrements `r0` and jumps to `:loop` if the result is nonzero. When `r0=0`, continue past the loop.

7.8.5 Conditionals

Spin

```
if x => 10
x := 0
' else
```

PASM

```
  cmp _cX, #10 wz, wc
if_nz_and_nc jmp #:cont
  mov _cX, #0

:cont
'else
```

The compare sets the Z flag if $X \equiv 10$ and the C flag if $X < 10$. So, if neither is set, then X must be greater than 10. The `if_nz_and_nc jmp #:cont` instruction will jump to `:cont` in that case.

7.9 Summary

Setting and reading pins are central tasks to the function of the Propeller. In PASM code you set and read pins by writing to the `outa` register and reading from the `ina` register, respectively. In general, you define a *mask* that is specific to a pin and then operate on that mask and the `ina`/`outa` registers.

In this book I try and document my code with comments and descriptive variable and method names. In addition I use TDD when possible. In Figure 7-7, is a picture of all the lubrication points on a locomotive: documentation and maintenance!

```
  mov dira, #0 wz ' set all pins to input, and set z=1
  ' mux <flag > <dest >, <source >
  ' the mux__ instructions set the bits of
  ' the <destination register > that are called out in the
  ' <source register > baseed on the value of <flag >
  '
  ' for example, here we set outa based _coutMask
  ' and NOT Z (!Z)
  muxnz outa, _coutMask
  ' here we set dira based on _coutMask and Z
  muxz dira, _coutMask

...
  ' here we toggle the bit in outa based on _coutMask
  xor outa, _coutMask

...
  ' here we set C from ina, based on the value of _cinMask
  test _cinMask, ina, wc
```

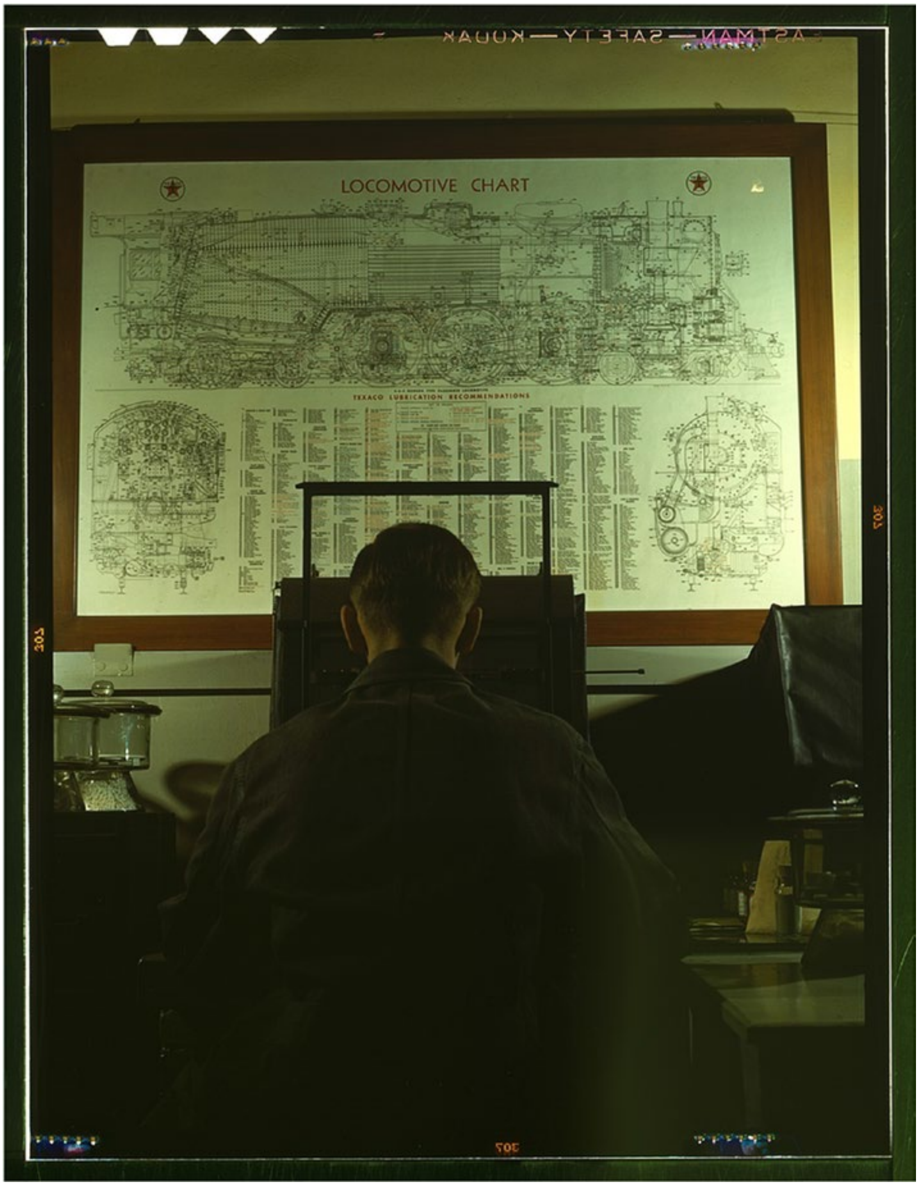


Figure 7-7. *Locomotive lubrication chart, Chicago and NW Railroad Laboratory, Chicago, IL. Photo by Jack Delano, 1942. From the Library of Congress Farm Security Administration archives.* `www.loc.gov/pictures/item/fsa1992000662/PP/`.

CHAPTER 8

Implementing the Compression Code in PASM

In this chapter and the next one, we will start to write some real PASM code to implement the compression. In this chapter, I will talk mainly about passing parameters to the PASM cog. In the next chapter, I will complete the compression and decompression code.

8.1 Passing Parameters to PASM

To reproduce the Spin code from `steim_spin` in PASM, we need to have a way to pass the addresses of `sampsBuf` and other arrays to the PASM cog. In Spin that was simple. `@sampsBuf` was the address, and it could be passed to the `COMPRESS` method, where the values could be accessed with `long[psampsBuf][j]`.

There are two main ways to pass information back and forth. Let's begin with the (in my opinion) simpler way, which is passing information in the `cognew` command.

We'll set up these files:

```
ch8/
├── steim_pasm0_Demo.spin
└── steim_pasm0.spin
```

8.2 Setting Up steim_pasm0

Create two new files: `steim_pasm0_Demo.spin` (Listing 8-1) and `steim_pasm0.spin` (Listing 8-2). Most of what is shown here is similar to what is in the pure-Spin version, but the compression will be done in PASM instead. First, we set up the `..._Demo.spin` file, which is the entry point.

Listing 8-1. steim_pasm0_Demo: Spin Side of the First Iteration of the PASM Compression

```
{* -*- Spin -*- *}
{* steim_pasm0_Demo .spin *}

CON ' Clock mode settings
  _CLKMODE = XTAL1 + PLL16X
  _XINFREQ = 6 _250_000

  ' system freq as a constant
  FULL_SPEED = (( _clkmode - xtal1) >> 6) * _xinfreq
  ONE_MS = FULL_SPEED / 1_000 ' ticks in 1ms
  ONE_US = FULL_SPEED / 1 _000_000 ' ticks in 1us

CON ' Pin map

  DEBUG_TX_TO = 30
  DEBUG_RX_FROM = 31

```

```
CON ' UART ports
  DEBUG = 0
  DEBUG_BAUD = 115200

  UART_SIZE = 100
  CR = 13
  LF = 10
  SPACE = 32
  TAB = 9
  COLON = 58
  COMMA = 44

OBJ
  '1 COG for 3 serial ports
  UARTS : "FullDuplexSerial4portPlus_0v3"
  NUM : "Numbers" 'Object for writing numbers to debug
  COMPR : "steim_pasm0"

CON
  NSAMPS_MAX = 128

VAR
  long nsamps, ncompr
  long sampsBuf[NSAMPS_MAX]
  long comprCodeBuf[NSAMPS_MAX >> 4]

  byte mainCogId, serialCogId, comprCogId
  byte packBuf[NSAMPS_MAX << 2]

PUB MAIN

```

```
' main cog
mainCogId := cogid

' uart cog
LAUNCH_SERIAL_COG
PAUSE_MS(500)

UARTS.STR(DEBUG, string(CR, " Compression ", CR, LF))
UARTS.STR(DEBUG, string(" mainCogId : "))
UARTS.DEC(DEBUG, mainCogId)
UARTS.PUTC(DEBUG, CR)
UARTS.PUTC(DEBUG, LF)

' compression cog
COMPR.INIT(NSAMPS_MAX)
comprCogId := COMPR.START

UARTS.STR(DEBUG, string(" comprCogId : "))
UARTS.DEC(DEBUG, comprCogId)
UARTS.PUTC(DEBUG, CR)
UARTS.PUTC(DEBUG, LF)

nsamps := 1
ncompr := COMPR.COMPRESS (@sampsBuf, nsamps, ↩
@packBuf, @comprCodeBuf)

UARTS.STR(DEBUG, string(" ncompr : "))
UARTS.DEC(DEBUG, ncompr)
UARTS.PUTC(DEBUG, CR)
UARTS.PUTC(DEBUG, LF)
```

```
78      repeat
79        PAUSE_MS(1000)
80
81  PRI LAUNCH_SERIAL_COG
82  " method that sets up the serial ports
83    NUM.INIT
84    UARTS.INIT
85    UARTS.ADDPORT (DEBUG, DEBUG_RX_FROM, DEBUG_TX_TO, -1, ➥
      -1, 0, %000000, DEBUG_BAUD) 'Add DEBUG port
86    UARTS.START
87    serialCogId := UARTS.GETCOGID 'Start the, ports
88    PAUSE_MS(300)
89
90  PRI PAUSE_MS(mS)
91    waitcnt(clkfreq /1000 * mS + cnt)
92
93  ' Program ends here
```

- **Line 34**: Import the file `steim_pasm0.spin` as object `COMPR`.
- **Lines 63–64**: Initialize and start the compression cog. As you will see, the `COMPR.START` function (a Spin function) launches a new PASM cog.
- **Lines 71–72**: Call the Spin method `COMPR.COMPRESS` (a Spin function), which signals the PASM cog to compress the samples in `sampsBuf`.

We will start by implementing the simplest possible compression code in Spin and PASM code in `steim_pasm0`. It includes passing `nsamps` to the PASM cog and reading `ncompr` back. As I said earlier, the PASM code has to monitor the hub memory and react to a change. Here we use `nsamps` as the trigger. If the value is greater than zero, then perform a compression, and at the end of the compression, set `ncompr` to a nonzero value. That, in turn, will be the signal to the Spin code that the PASM cog has completed its work. In this first example, that work is simple: you don't have to do anything! The compressor will simply set `ncompr` to a nonzero value and return to monitoring `nsamps`.

The `steim_pasm0.spin` file starts out looking like Listing 8-2.

Listing 8-2. First Version of steim_pasm0.spin Showing the Spin Methods and the Beginning of the PASM Code

```
CON
    CODE08 = %01
    CODE16 = %10
    CODE24 = %11

VAR
    byte ccogid
    long mymax

    long myns, myncompr

PUB INIT(nsmax)
    mymax := nsmax
    ccogid := -1

PUB START
    STOP
    ' myns <> 0 controls when the compression is started
    myns := 0
    ccogid := cognew (@STEIM, @myns)
    return ccogid

```

```
PUB STOP
     if ccogid <> -1
        cogstop (ccogid)

PUB COMPRESS(psampsBuf, ns, ppackBuf, pcomprCodeBuf) : ncompr
" Inputs : psampsBuf - address of long array of samples ↵
(max len, mymax)
"'          ns - number of samples to compress
"           ppackBuf - address of byte array of packed data
"           pcomprCodeBuf - address of long array of ↵
            compression, codes
" Output : ncompr - number of bytes in packBuf
"
" Modified : packBuf and comprCodeBuf are changed

    myns := 0
    myncompr := 0

    ' this will start the compression
    myns := ns

    ' when ncompr is non -zero, the compression is complete
    repeat until myncompr > 0
    return myncompr

PUB DECOMPRESS(psampsBuf, ns, ppackBuf, ncompr, ↵
pcomprCodesBuf) : ndecomp
    return 0

DAT 'steim
```

```
"
"

STEIM org 0
  ' copy the param addresses
  mov _cnsPtr, par
  mov _cncomprPtr, par

  add _cncomprPtr, #4

: mainLoop
   ' the signal for starting the compression is when ns <> 0
   rdlong _cns, _cnsPtr wz
   if_z jmp #:mainLoop

   ' signal completion
   mov _cncompr, #3
   wrlong _cncompr, _cncomprPtr

   ' wait for another compression request
   jmp #:mainLoop

' const
_ccode24 long CODE24
_ccode16 long CODE16
_ccode08 long CODE08

_cnsPtr res 1
_cncomprPtr res 1

_cns res 1
```

```
81  _cncompr res 1
82
83  r0 res 1
84
85      FIT 496
```

- **Line 10**: The variables `myns` and `myncompr` are declared one after the other, so they will be stored in hub memory one after the other. This property of storage is used in the PASM cog to find these variables. In other words, be careful about rearranging variable declaration order!
- **Lines 16–21**: We start the compression cog with `cognew` (after stopping any already running cog). The command `cognew(@STEIM, @myns)` says to copy the code in the `DAT` section (lines 49–85) into a new cog and to launch that cog. In addition, the address of the variable `myns` (a hub address) is also passed to the cog.
- **Lines 27–44**: Here the actual compression will take place. When `myns` is set to a nonzero number, the compression cog will notice that and will then begin the compression. When the cog has completed the compression, it will set `myncompr`, the length of the packed buffer `packBuf`, to a positive number.
- **Lines 46–47**: The decompression routine does nothing for now.
- **Lines 53–58**: This is the heart of the *parameter passing* to the cog. The address of `myns` (a hub address) is copied to `_cnsPtr` (a cog address), and the address of `myncompr` is copied to `_cncomprPtr`. You'll learn much more about this in the next chapter.

- **Lines 60–63**: Here the cog sits in a loop, continually copying the value of myns from its hub location (earlier, we copied @myns to _cnsPtr) to _cns. It checks whether myns is nonzero (which is the wz effect that you'll learn more about later); if it is still zero, it jumps back up to :mainLoop.
- **Lines 66–70**: The program arrives here if myns is nonzero, at which point we set myncompr to 3. This is done by setting _cncompr to 3 and then copying that value to hub memory. Then the program jumps back around to :mainLoop and repeats.
- **Lines 73–83**: Reserve space for some cog variables (I like to prepend the variable names with c to indicate they are local to the cog). I also have some temporary register variables (here r0).

OK, let's break this code down.

The CON section defines the codes for the compression. For example, if a difference value δ_j can be stored in 1 byte, then we write CODE08 in the comprCodeBuf (at the location corresponding to the j-th sample).

Pay particular attention to the VAR section where we have two long variables *one right after the other*.

```
long myns, myncompr
```

This means they are stored in consecutive locations in hub memory.

Next we have the INIT, START, and STOP methods. The START method has the following command:

```
ccogid := cognew(@STEIM, @myns)
```

This starts a new cog and returns the cog number if successful (or -1 if eight cogs are already running). To reiterate, the Propeller has eight independent processors or cogs. When you first run `steim_pasm0_Demo`, one cog starts up and runs all the code in `MAIN`. When `MAIN` calls `COMPR.START`, which runs `cognew`, a *new cog is launched*. The contents of this cog are the PASM instructions in the `DAT` section labeled `STEIM` (starting at line 53 and continuing to the `FIT` instruction at line 85). From this point forward, the `STEIM` cog is entirely independent (if you are coming from the C world, this is a `fork` and `exec...`). The only way for the `MAIN` cog and the `STEIM` cog to interact is for one of them to change variables in hub memory…and for the other cog to react to that change.

This means that each cog has to periodically check the same location in hub memory and has to include logic to decide that something must be done. Let's look at the parameter passing in more detail.

8.3 Passing Parameters in the cognew Command

The `cognew` command takes two arguments: the PASM cog to launch (`@STEIM`) and the address of a variable to share (here `@myns`).

```
ccogid := cognew (@STEIM, @myns)
```

When Spin encounters the command `cognew`, it does two things: it copies the PASM code into cog memory, *and* it places the value of the second argument to `cognew` (`@myns`—the memory location where the value `myns` lives) into the location `PAR` in cog memory. (`PAR` is always `0x1F0`.) The `STEIM` cog can now get `@myns` from `PAR`, and using the `rdlong` and `wrlong` commands, it can read and change `myns`. The main cog (and other cogs) can also read and change `myns`, so there will need to be some protocol for making sure they don't collide. (In other words, if the `STEIM` cog reads `myns` and then writes a new value there some time later, we can't allow the `main` cog to mess with it during that time.)

An Analogy to PAR Consider a train station—one of those lovely, high-ceiling Central European train stations filled with spies, intrigue, and good coffee. There is a room off to the side with rows of lockers (or at least back in the innocent days of my youth there were...). Each locker has a number. In this train station, there are only a few people: an elegant young woman with the odd name of Ms. Main Cog (`main` for short) and an older gentleman named Mr. Joe Steim (`steim` for short). They want to communicate, but they don't know what the other looks like.

When `main` wants to give `steim` a message, the only way she can do so is to place the message in a locker. `steim` can then open the locker and read and modify the message. `main` can come back some time later and re-open the locker and read what `steim` did. There is still a problem, though. `main` needs to tell `steim` which locker to open. This is where the information desk comes in (every train station has one, with some wonderfully patient, friendly, and knowledgeable folks). Before `steim` arrives (with the `cognew` command), `main` chooses a locker where she is going to leave messages and tells the lady at the information desk the locker number. When `steim` arrives, he goes to the information desk and asks "Did `main` leave a locker number for me?" *Voilà*. Both `main` and `steim` can now communicate.

The expression `@myns` is the address (the "locker number") of the variable `myns`. When passed to `cognew`, `cognew` places this address in a location known to everybody, called PAR (the "information desk" of my analogy).

8.3.1 Using PAR

The Spin code has this:

```
cognew(@STEIM, @myns)
```

The PASM cog has the statements shown in Listing 8-3.

Listing 8-3. PASM Fragment for Passing Parameters Using par

```
mov _cnsPtr, par
...
_cnsPtr res 1
```

The `mov_cnsPtr, par` instruction copies the address stored in `PAR` (this is the "information desk" of my example) into the cog memory location `_cnsPtr`. The PASM cog also needs to reserve some space for that number, which it does with the `_cnsPtr res 1` statement.

8.3.2 Using PAR Some More

In the Spin code, the variables `myns` and `myncompr` are declared thusly:

```
VAR
  long myns, myncompr
```

Therefore, we know that these two variables occupy successive memory in the hub. So, for example, if `myns` is at memory location `0x14`, then `myncompr` will be at `0x18` (they are 4 bytes apart because they are `longs`). In Figure 8-1, the memory layout for the Hub and cog are shown.

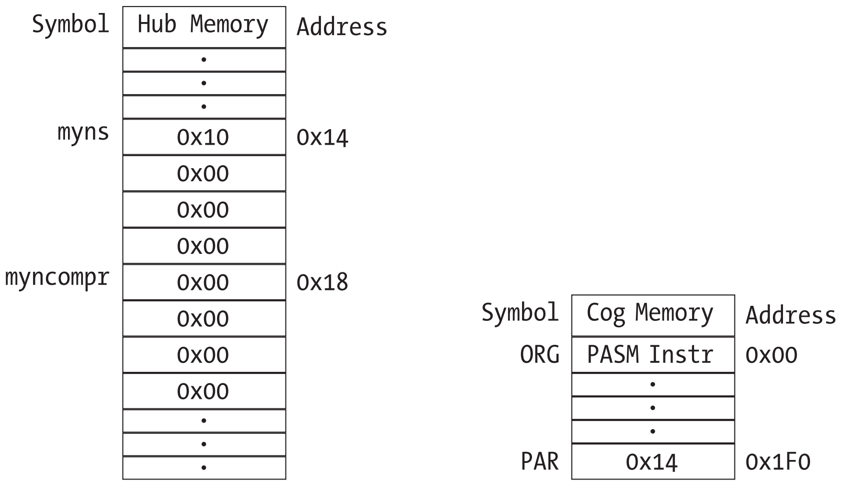


***Figure 8-1.** The layout of Hub memory (left) and cog memory (right) showing how parameters are passing using the par register*

When `cognew(@STEIM, @myns)` is called, the Propeller places the number `0x14` (the address of `myns`) into memory location `PAR`. We use our knowledge about the layout of hub memory to now find out how to access `myncompr`.

```
  mov _cnsPtr, par
  mov _cncomprPtr, par
  add _cncomprPtr, #4
...
_cnsPtr res 1
_cncomprPtr res 1
```

The instruction `mov _cnsPtr, par` copies `0x14` into `_cnsPtr`. The instruction `mov _cncomprPtr, par` *also* copies `0x14` into `_cncomprtPtr...`, but the next instruction, `add _cncomprPtr, #4`, adds 4 to that value with the result of `_cncomprPtr = 0x18`, which is just what we want.

8.3.3 Using the Addresses

Now that we have those addresses for `myns` and `myncompr`, we can access the actual values.

```
rdlong _cns, _cnsPtr wz
...
mov _cncompr, #3
wrlong _cncompr, _cncomprPtr
```

There are only two sets of instructions to access hub memory: `rdlong` and `wrlong` (and their sisters `rdbyte/wrbyte` and `rdword/wrword`). The following instruction does two things:

```
rdlong _cns, _cnsPtr wz
```

It copies whatever is in the hub memory location that is *pointed to* by `_cnsPtr` into `_cns`. (Again, `_cnsPtr` contains the number `0x14`; the `rdlong` instruction copies the `long` value that is stored at location `0x14` into the variable `_cns`.)

The second thing going on in that instruction is the `wz` *effect*. Every PASM instruction can have, as a side effect, the ability to change the flags `Z` and `C`. You have to read the manual to find out when and how `Z` and `C` are affected.

In the case of `rdlong _cns, _cnsPtr wz`, the `Z` flag is set to 1 (one) if the read operation results in a zero being written to `_cns`. If the read operation results in a nonzero value in `_cns`, then `Z` is set to 0 (zero). Read that paragraph a few times (and if it is unclear, drop us a line with suggestions!).

Now both cogs can do what they want with the variable `myns`.

8.3.4 Starting the Compression

The PASM cog continues after the instructions shown earlier and would continue to the end of cog memory except that we have some *branching* instructions.

```
:mainLoop
  rdlong _cns, _cnsPtr wz
  if_z jmp #:mainLoop
```

The expression `:mainLoop` is a *label*. It is a location that we can jump to. And we use that in this instruction:

```
if_z jmp #:mainLoop
```

The `rdlong` instruction sets `Z` according to whether `_cns` ends up being zero (in other words, whether `myns` in hub memory is zero or not). As long as `myns` is zero, then `_cns` will be zero, and therefore `Z=1`. The instruction `if_z jmp #:mainLoop` says that if `Z==1`, then jump to `:mainLoop`. If `Z≠1`, then continue to the next instruction. The reason for setting `Z` is so that we can make *branching* decisions based on whether `myns` is zero or not. As I said, the `STEIM` and `main` cogs are independent, and the way `main` asks `STEIM` to start a compression is by setting `myns` to the number of samples to compress (a nonzero value).

Once Ms. Main has asked Mr. Steim to start work (with the `cognew` command), he will periodically check the locker number `0x14` (named `_cnsPtr` in the PASM cog and `myns` in the main cog). If the note in there has the number zero on it, he will go back to cafe and get another espresso. If it has a nonzero number, then he knows he has work to do.

8.4 Passing Parameters: Method 2

The second way to pass parameters is to write a hub address to a cog variable *before* it is launched.

In the previous sections, we used the special memory location PAR to pass the address of a variable to the PASM cog.

To go back to Ms. Main and Mr. Steim passing messages in the train station, `main` launches `steim` with the `cognew` command. You can think of that action as if Mr. Steim were handed a book with 512 pages. He reads the instruction on page 0 and does as instructed; he moves on to page 1, and so on. Well, before you hand him the book, go to, for example, page `0x100` (oddly enough, both Ms. Main and Mr. Steim think in hex!) and write down the number of a locker that you want to share with him. Now both of you know the locker (and you don't have to get the information desk involved).

To review, the `cognew` command copies instructions, variables, reserved space, and special registers to a new cog (512 longs worth, of which the user has access to 496), as shown in Listing 8-4.

Listing 8-4. PASM Fragment Showing Cog Memory Layout

```
PUB START
...
  ccogid:= cognew(@STEIM, @myns)
...

DAT 'pasm cog
STEIM ORG 0

```

```
... instructions
  rdlong _cns, _cnsPtr wz

... variables
_ccode24 long CODE24

... reserved space
_cnsPtr res 1

FIT 496
... system registers (PAR, CNT, etc)
```

For the cog to access a hub array such as `logBuf`, we will do the following:

1. We will define a new array in Spin called `logBuf`. (This is like deciding on a locker number.)
2. We will define a new variable in the PASM code called `_clogBufPtr`. (This is the "page number" `0x100` in the book of instructions that Mr. Steim is given.)
3. Before the cog is launched, we will place the address of `logBuf` into `_clogBufPtr`. (We write down the locker number on the correct page.)

We are, in effect, dynamically writing the PASM code, as shown in Listing 8-5.

Listing 8-5. PASM Fragment Showing Memory Layout for Passing Array Address in a Register

```
CON
  LOGLEN = 256

VAR
```

```
  logBuf[LOGLEN]

PUB START
  _clogBufPtr := @logBuf
  ccogid := cognew(@STEIM, @myns)
...

DAT 'pasm cog
STEIM ORG 0

... instructions
  rdlong _cns, _cnsPtr wz

... variables
_ccode24 long CODE24

_clogBufPtr long 0

... reserved space
_cnsPtr res 1

FIT 496
... system registers (PAR, CNT, etc)
```

The instruction in the Spin code *just before* the cognew command, _clogBufPtr := @logBuf, is like writing down a locker number in the book.

The layout of memory in Hub and cog are shown in Figure 8-2.

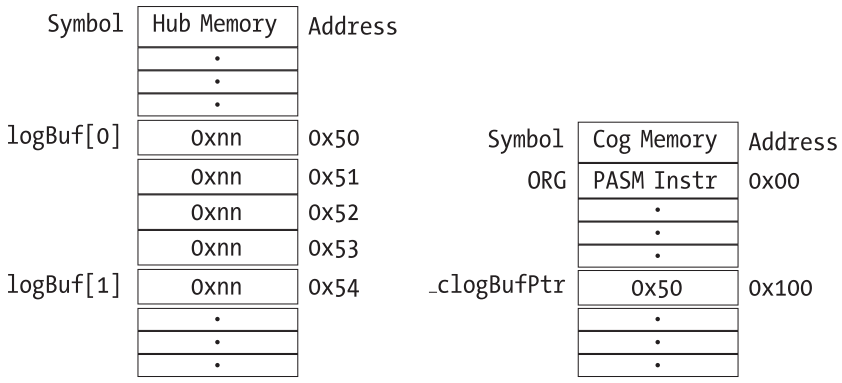


Figure 8-2. *The layout of memory in Hub and cog when we are passing parameters using an address written to a variable (method 2 of parameter-passing)*

Now both the Spin cog and the PASM cog can read and write from `logBuf`. The Spin cog can access `logBuf[j]` directly, and the PASM cog can access it using the `rdlong/wrlong` instructions to address `_clogBufPtr`. I will use this array in Chapter 11.

Naming Variables The naming of variables should follow a pattern. Use a prefix for variables local to the cog followed by a short name for the variable (e.g., `cns`). Those variables that are addresses of variable ("locker numbers") should have `Ptr` appended (`cnsPtr`). I use `c` as a prefix for variables within the scope of the cog. This reduces the possibility of inadvertently using the wrong variable.

8.5 Summary

In this chapter, we looked at two different ways of passing data into and out of cogs. The first method is to place the address of a variable into the PAR register when a new cog is launched. The PASM cog can now read and write to that location (and to subsequent locations, if they also have variables of interest).

The second way is to store the address of a variable in a location that both the Spin and PASM code know about. This is done before the PASM cog is launched. There is no need to involve PAR in this case. See Listing 8-6 for a template for these two ways of passing parameters.

In Figure 8-3 we show an actual Information Desk at the old Penn Station in New York (sadly torn down in the 1960s).

Listing 8-6. A template for passing parameters from Spin to PASM cogs

```
VAR
  'variable1 and variable2 are stored in successive locations
  long variable1, variable2
  ' this variable will be passed to the cog by storing
  ' it 's value in a PASM variable BEFORE launch
  long variable3

PUB MAIN
  ' 1. cognew command will store the address of variable1
  ' in PAR and then launch MYCOG in a new cog
  ' 2. before we launch MYCOG, we place the address of ➥
  variable3
  ' into _cvariable3Ptr, which will be available to the cog
  _cvariable3Ptr := @variable3
  cognew(@MYCOG, @variable1)

DAT
MYCOG org 0
  mov _cvar1Ptr, par ' when mycog is launched, ↩
                     ' par contains the ↩
                     ' address of variable1
  mov _cvar2Ptr, par ' the next long location ↩
                     ' contains the address
  add _cvar2Ptr, #4 ' of variable2

  rdlong _cvar1, _cvar1Ptr ' the actual value of variable1
                           ' is obtained by a rdlong
  rdlong _cvar2, _cvar2Ptr

  rdlong _cvar3, _cvariable3Ptr ' _cvar3Ptr is populated ↩
                                  with the address
                                ' variable3 BEFORE launch, ↩
                                  so no need for par

_cvariable3Ptr long 0 ' variable where the address of ↩
                        variable3
                      ' will be written BEFORE launch of cog
_cvar1Ptr res 1       ' space for the ptrs and vars that are
_cvar2Ptr res 1       ' passed thru par
_cvar1 res 1
_cvar2 res 1
_cvar3 res 1
```

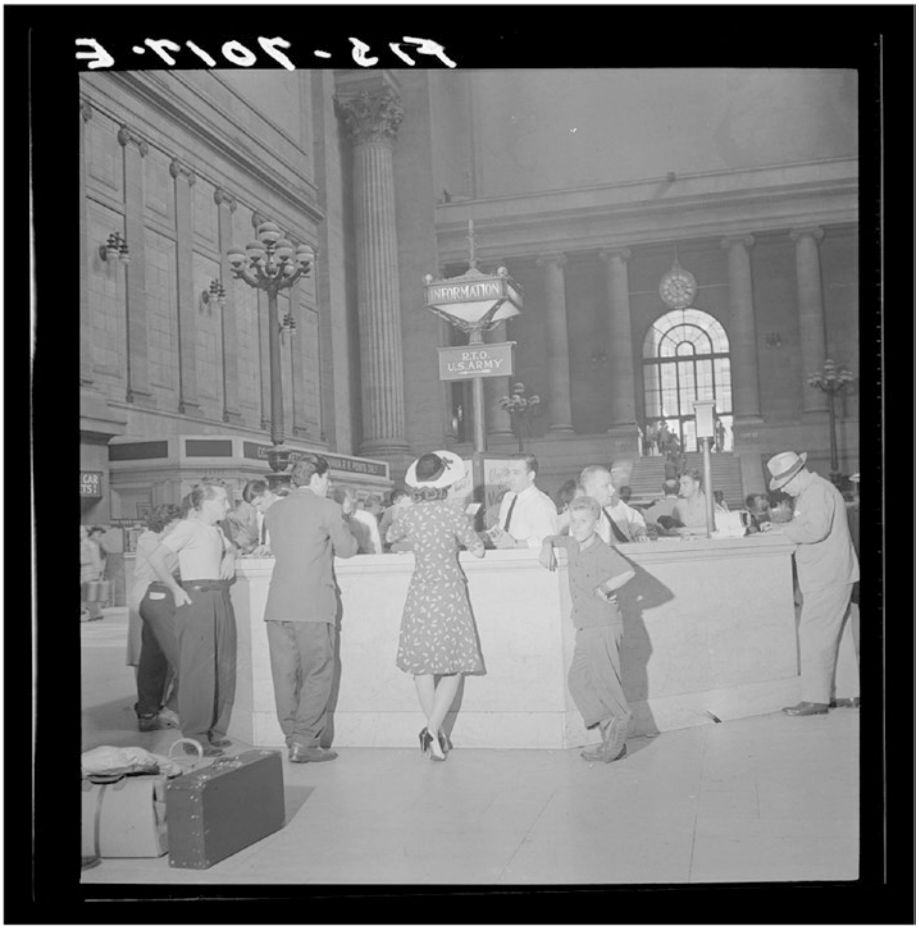


Figure 8-3. *Information desk at the old Pennsylvania Station in New York.* https://commons.wikimedia.org/wiki/File:Information_booth_at_the_Pennsylvania_railroad_station8d21848v.jpg.

CHAPTER 9

Compression in PASM with TDD

Let’s convert our Steim compressor to PASM using TDD. The specification in Chapter 5 is written for a “traditional” language where the compression routine is called by the main program (as in our Spin example). As we want to implement the compression routine in PASM, we will start a new cog and will have to perform *handshaking*, as it is called, between the two cogs as follows (Figure 9-1):

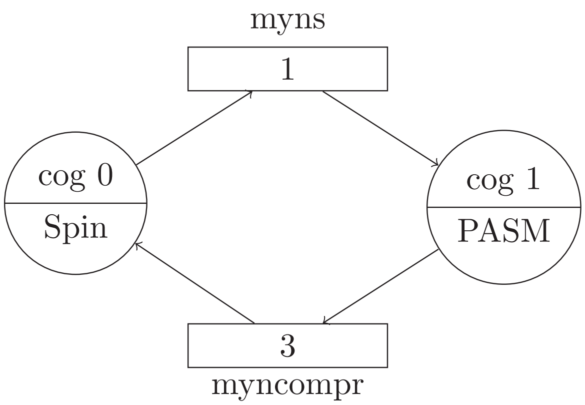
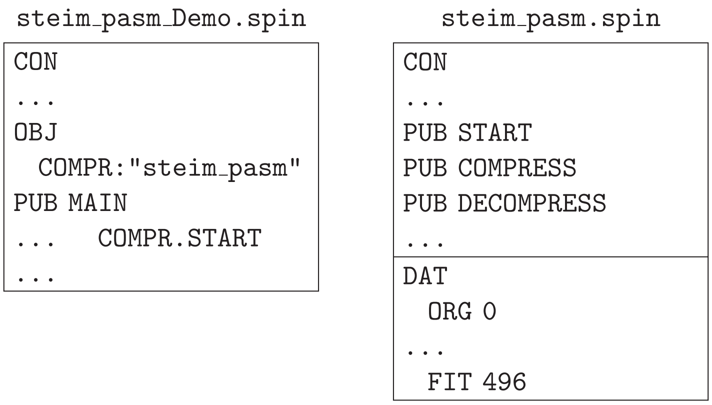


Figure 9-1. *Diagram showing the handshaking between the Spin cog and the PASM cog*

S. Anandakrishnan, *Propeller Programming*, https://doi.org/10.1007/978-1-4842-3354-2_9

As shown in Figure 9-1, the main Spin cog will set `myns` to a nonzero value, which will trigger the PASM cog to perform the compression. When the PASM cog finishes its work, it will set `myncompr` to a nonzero value, which signals the main cog that the compression is complete.

Let's look at the "file view" and "cog view" of the project. The Spin code is split between the main file (`steim_pasm_Demo`) and the actual compressor file (`steim_pasm`), shown in Figure 9-2. The main file and the compressor file are related as shown in Figure 9-2: the main or driver file includes the worker file using the OBJ keyword.



steim_pasm_Demo.spin

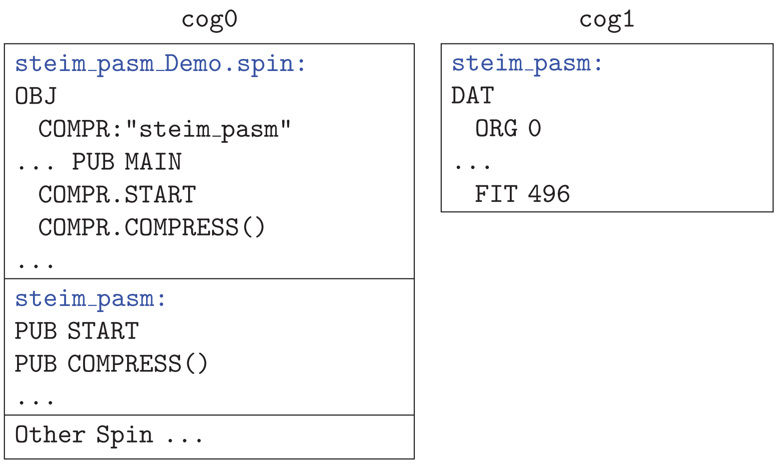
```
CON
...
OBJ
  COMPR:"steim_pasm"
PUB MAIN
...   COMPR.START
...
```

steim_pasm.spin

```
CON
...
PUB START
PUB COMPRESS
PUB DECOMPRESS
...
DAT
  ORG 0
...
  FIT 496
```

Figure 9-2. *The file-level view of the compression program, with the driver file on the left and the worker file on the right*

The cog view of the project is (in part) as follows: cog0 runs main and the Spin methods in `steim_pasm`. cog1 runs the PASM code for the compression and decompression (Figure 9-3). The PASM code is triggered by changes in hub memory (when `myns` is set to a nonzero value).



```
steim_pasm_Demo.spin:
OBJ
  COMPR:"steim_pasm"
... PUB MAIN
  COMPR.START
  COMPR.COMPRESS()
...
```

```
steim_pasm:
PUB START
PUB COMPRESS()
...
```

```
Other Spin ...
```

```
steim_pasm:
DAT
  ORG 0
...
  FIT 496
```

Figure 9-3. *The cog-level view of the compression program*

The files for this program are on GitHub.

```
ch9/
 ├── steim_pasm_Demo.spin
 └── steim_pasm.spin
```

9.1 Overall Flowchart

Figure 9-4 shows the flowchart for the PASM cog. When $N > 0$ (`myns`), the cog will read and process a sample. Every 16th sample, it will write out a compression code long. Upon completion, it will write out the last compression code long. It will set $N = 0$ and write out the number of bytes used in the compression, N_c (`myncompr`).

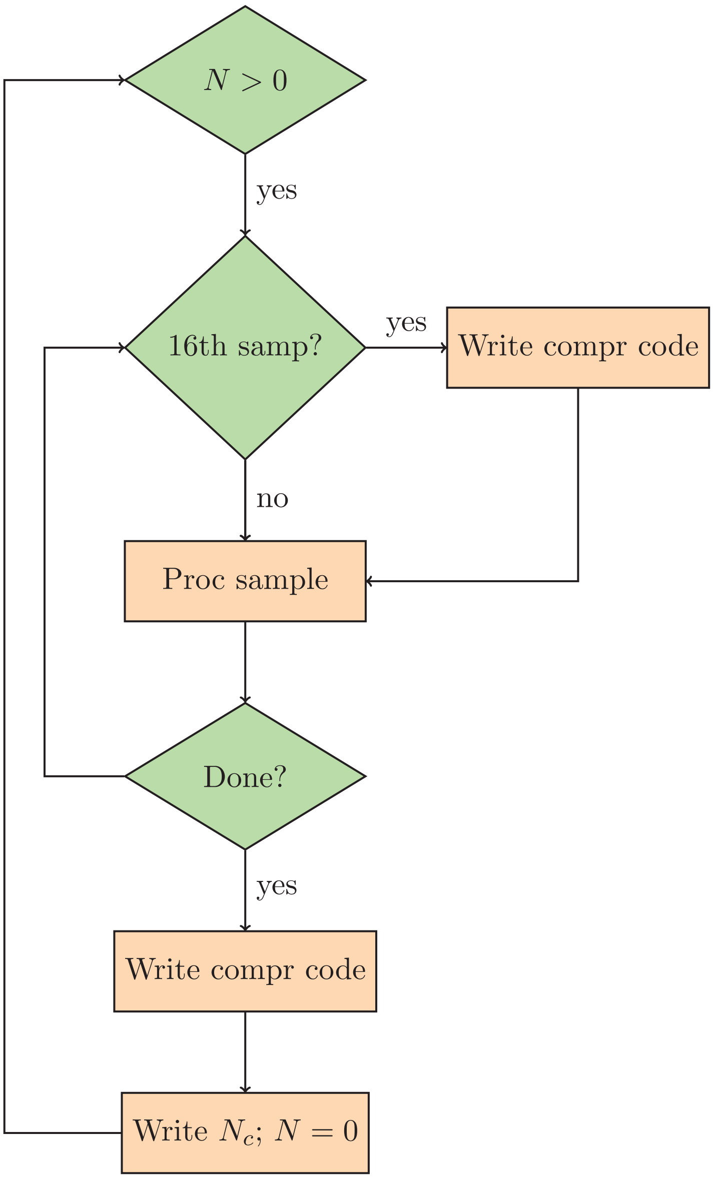


***Figure 9-4.** Flowchart for compression of samples*

9.2 Test 1: Passing nsamps and ncompr

Let's write a test for a small part of this: setting `myncompr` to non-negative. The test will do the following:

1. The calling cog (`main`) will set the number of samples (`myns` in the `COMPR` object) to the number of samples in `sampsBuf`.
2. Upon completion of compression, the `STEIM PASM` cog will set the number of compressed bytes (`myncompr`) to a non-negative number.

9.2.1 Spin Code

Listing 9-1 shows the Spin code. Add it to `main`.

Listing 9-1. Spin Code

```
PUB MAIN
...

  TEST_THAT_NCOMPR_IS_SET_TO_NONNEGATIVE

...
PUB TEST_THAT_NCOMPR_IS_SET_TO_NONNEGATIVE | nc, t0
" test methods are rarely commented - the name should be
" explanatory ...
  nsamps := 1
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf)
  t0 := nc => 0
  TDD.ASSERT_TRUTHY (t0, string("Test that the compression ↩
  cog sets ncompr => 0"))
```

The test is relatively simple. The test method in `main` sets `nsamps` to 1 and calls `COMPR.COMPRESS`. Within the `COMPRESS` object, `myns` is set to 1, which triggers the compression.

9.2.2 PASM Code

Listing 9-2 shows the `START` code that launches the PASM cog, the `COMPRESS` code, and the PASM code from the previous chapter with the *handshaking* discussed in detail.

Listing 9-2. PASM Code

```
...
PUB START
    STOP
'   myns <> 0 controls when the compression is started
    myns := 0
    ccogid := cognew(@STEIM, @myns)
    return ccogid

PUB COMPRESS(psampsBuf, ns, ...)
...
  myns := 0
  myncompr := 0

  ' this will start the compression
  myns := ns

  ' when ncompr is non -zero, the compression is complete
  repeat until myncompr > 0
  return myncompr
```

```
...

STEIM org 0
  ' copy the param addresses
  mov _cnsPtr, par
  mov _cncomprPtr, par
  add _cncomprPtr, #4

: mainLoop
   ' the signal for starting the compression is when ns <> 0
   rdlong _cns, _cnsPtr wz
   if_z jmp #:mainLoop

   ' set myns to zero first so we don't start another ↩
   cycle ...
   mov _cns, #0
   wrlong _cns, _cnsPtr

   ' signal completion
   mov _cncompr, #3
   wrlong _cncompr, _cncomprPtr

   ' wait for another compression request
   jmp #:mainLoop
```

The START function is called once by the driver file, and that starts the PASM cog. The COMPRESS function can be called any number of times, and it communicates with the (running) PASM cog via the value of myns. When the COMPRESS function sets myns := ns, that sets myns to 1. The running PASM cog is continually monitoring myns (via the rdlong in the steim cog that sets _cns). Because of the wz effect of the rdlong, the instruction will set Z to 0 when _cns is nonzero. Now, instead of jumping back around to :mainLoop, control will pass to the next instructions:

```
' set myns to zero first so we don't start another cycle...
mov _cns, #0
wrlong _cns, _cnsPtr
mov _cncompr, #3
wrlong _cncompr, _cncomprPtr
' wait for another compression request
jmp #:mainLoop
```

Next, we set _cns to zero and write that back to hub memory (to myns) so that when we go back up to :mainLoop, we don't immediately start another compression cycle. Finally, we set the variable _cncompr to 3 and then write that value to hub memory (to myncompr) with the wrlong instruction.

In the Spin code in COMPRESS, the following statement will loop at that line continuously until myncompr is greater than zero, which it will be soon, when the PASM code does its wrlong!

```
repeat until myncompr > 0
```

At that point, the Spin code will continue to the next instruction.

```
return myncompr
```

Back in the calling function, nc will be set to 3, the value t0 will be true, and the ASSERT_TRUTHY call will print OK.

```
nc := COMPR.COMPRESS(@sampsBuf, nsamps, @packBuf,
@comprCodeBuf)
t0 := nc => 0
```

9.3 Test 2: Packing Sample 0

In the previous section, we passed `nsamps` to the `steim` cog, which signals the start of the compression process. In this section, we will actually compress sample 0 and populate `packBuf` and `comprCodeBuf`. If you recall from the specification and from the Spin code examples, the three low bytes of `sampsBuf[0]` are placed in `packBuf`, and the code for a 3-byte compression is placed in the low 2 bits of `comprCodeBuf[0]`.

9.3.1 Spin Code

To read from `sampsBuf` and write to the other two arrays, we need to pass their addresses to the `steim` cog. Listing 9-3 shows the modified calling routine, with three new tests that check whether sample 0 is packed correctly, whether `ncompr` is set correctly (to 3), and whether `comprCodeBuf[0]` is set correctly to `COMPR.CODE24`.

Listing 9-3. Driver File Testing Code

```
PUB MAIN
...

  TEST_THAT_SAMP0_IS_PACKED_PROPERLY
  TEST_THAT_SAMP0_SETS_NCOMPR_TO_3
  TEST_THAT_SAMP0_SETS_COMPRCODE_TO_CODE24

...
PUB TEST_THAT_SAMP0_IS_PACKED_PROPERLY | t0, nc
  sampsBuf[0] := $AB_CD_EF
  nsamps := 1
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf)
  t0 := (packBuf[0] == sampsBuf[0] & $FF)
  t0 &= (packBuf[1] == sampsBuf[0] >> 8 & $FF)
  t0 &= (packBuf[2] == sampsBuf[0] >> 16 & $FF)
  TDD.ASSERT_TRUTHY(t0, string(" Test that samp0 is packed ↩
  correctly into packbuf "))

PUB TEST_THAT_SAMP0_SETS_NCOMPR_TO_3 | t0, nc
  sampsBuf[0] := $AB_CD_EF
  nsamps := 1
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf )
  t0 := nc == 3
  TDD.ASSERT_TRUTHY(t0, string("Test that samp0 sets ↩
  ncompr =3"))

PUB TEST_THAT_SAMP0_SETS_COMPRCODE_TO_CODE24 | t0
  sampsBuf[0] := $AB_CD_EF
  nsamps := 1
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf)
  t0 := comprCodeBuf[0] == COMPR#CODE24
  TDD.ASSERT_TRUTHY(t0, string("Test that samp0 sets ↩
  comprCodeBuf to CODE24"))
```

9.3.2 Memory Layout of Arrays and Parameters

As in the previous section, we now need to pass the addresses of `sampsBuf`, `packBuf`, and `comprCodeBuf` as well to the `steim` cog.

Modify the VAR declaration for myns and myncompr to now include three new variables: sampsBufAddr, packBufAddr, and comprCodeBufAddr. These variables are all listed one after the other, so they occupy successive long locations.

There is one crucial difference, however, between myns and sampsBufAddr: the number stored at location @myns/0x14 is the *actual value of myns* (1). The number stored at sampsBufAddr/0x1C is *the address of the location* where sampsBuf lives in hub memory; here I have put in some arbitrary number as an example (0x104). In Figure 9-5, I show the layout of hub memory with the longs following @myns (myncompr, sampsBufAddr, etc.). The array sampsBuf itself is in a different part of memory, but its address is in sampsBufAddr, which will be made available to the PASM cog. You need to do this "indirect addressing" when you want to pass the address of an array that is stored elsewhere.

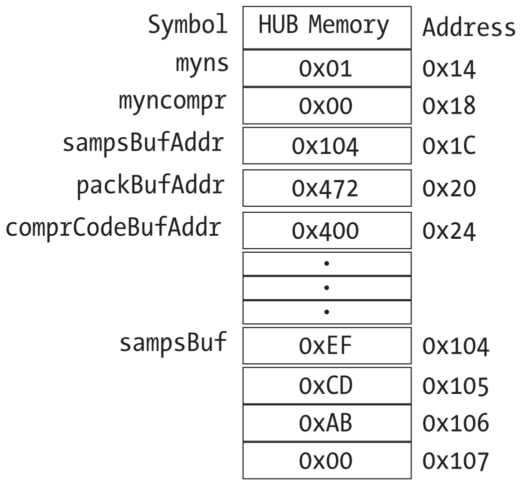


Figure 9-5. *Memory layout in hub showing the arrangement of variables that will be passed to the PASM cog. sampsBufAddr contains the address to the first sample of sampsBuf, which is shown further along in memory.*

The `COMPRESS` method gets those values because the calling routine passes `@sampsBuf` (the address of `sampsBuf`), and this is similar for the other two arrays.

Those three addresses are stored in the variables `sampsBufAddr`, `packBufAddr`, and `comprCodeBufAddr`, and when `myns` is set to nonzero, the `steim` cog will start the compression, using those addresses.

```
VAR
  long myns, myncompr, sampsBufAddr, packBufAddr,
comprCodeBufAddr

PUB COMPRESS(psampsBuf, ns, ppackBuf, pcomprCodeBuf) : ncompr
  sampsBufAddr := psampsBuf
  packBufAddr := ppackBuf
  comprCodeBufAddr := pcomprCodeBuf
  ' this will start the compression
  myns := ns
```

9.3.3 PASM Code

In the PASM code, we have already looked at how to access `myns`; now let's look at how to access `sampsBuf[0]` using *indirect addressing* (Listing 9-4).

Listing 9-4. Indirect Addressing in PASM to Read from an Array

```
...
: mainLoop
   ' the signal for starting the compression is when ns <> 0
   rdlong _cns, _cnsPtr wz
   if_z jmp #:mainLoop

   ' get the array start addresses
   mov r0, par
   add r0, #8
```

```
10      rdlong _csampsbufPtr, r0
11
12      mov r0, par
13      add r0, #12
14      rdlong _cpackbufPtr, r0
15
16      mov r0, par
17      add r0, #16
18      rdlong _ccomprcodebufPtr, r0
19
20      call #GET_SAMPLE
21      call #HANDLE_SAMP0
22
23      ' set myns to zero first so we don't start another ↩
        cycle ...
24      mov _cns, #0
25      wrlong _cns, _cnsPtr
26      ' signal completion
27      wrlong _cncompr, _cncomprPtr
```

- **Lines 8–9**: Copy the contents of PAR (the address of myns) to a temporary variable r0 and add 8 to it. Now r0 will have the address of the *location that has the address* of sampsBuf (0x1C).
- **Line 10**: The rdlong gets that address so that _csampsBufPtr is set to 0x104 (the address of the sampsBuf array in the hub).

We then copy the contents of the long at 0x1C to csampsbufPtr: csampsbufPtr = 0x104. We now have the location of sampsBuf[0]. We go through a similar procedure for the other two arrays, packBuf and comprCodeBuf.

9.3.4 Subroutines in PASM

As in other languages, you can define a subroutine when there is code that is often repeated or simply to keep your code modular and organized. In this case, I define two subroutines: GET_SAMPLE and HANDLE_SAMP0.

Subroutines are defined by enclosing them between two labels: SUBROUTINE_NAME and SUBROUTINE_NAME_ret. In addition, the second label (SUBROUTINE_NAME_ret) should be immediately followed by the PASM instruction ret. There are no formal arguments or parameters for the subroutine. Rather, the subroutine is in the same scope as the calling code. All variables are available and can be read and modified. Therefore, it is important to be clear on which variables are needed by the subroutine and which are modified. In Listing 9-5, I show the GET_SAMPLE and HANDLE_SAMP0 subroutines. The comments at the start show which variables are read and which are modified.

Listing 9-5. Examples of subroutines, with comments showing variables that are used and modified

```
GET_SAMPLE
" read a sample from sampsBuf
" modifies samp
" increments sampsbufPtr to next sample
  rdlong _csamp, _csampsbufPtr
  add _csampsbufPtr, #4
GET_SAMPLE_ret ret

HANDLE_SAMP0
" write the three bytes of samp to packbuf
" write code24 to comprcodebuf [0]
" destroys samp
" modifies ncompr

```

```
  mov r0, #3
:s0loop
   wrbyte _csamp, _cpackbufPtr
   add _cpackbufPtr, #1
   shr _csamp, #8
   djnz r0, #:s0loop
   ' loop terminates here
   mov _cncompr, #3
   mov _ccomprcode, _ccode24
   wrlong _ccomprcode, _ccomprcodebufPtr
HANDLE_SAMP0_ret ret
```

GET_SAMPLE is straightforward. It reads a long from the *current index* of sampBuf (initially 0) and increments the index to point at the next value in sampsBuf.

HANDLE_ SAMP0 takes that sample and writes the low 3 bytes back to packBuf. The following sequence is like a repeat 3 in Spin or a for loop in C. Set r0 to the number of times you want to loop and, at the end of the loop, decrement it by 1 and test for when it is equal to 0 (djnz r0, #:s0loop says "decrement r0 and jump to s0loop if r0 is not zero"). After three times, the loop terminates, and the instructions following djnz are executed.

```
  mov r0, #3
:s0loop
  <<do something>>
  djnz r0, #:s0loop
<<here after 3 iteration>>
```

The "do something" part is where the 3 bytes of sampsBuf[0] are copied to packBuf. The instruction wrbyte _csamp, _cpackbufPtr will copy the lowest byte of _csamp to the current address in _cpackbufPtr. The next instruction, add _cpackbufPtr, #1, will add the *literal value* 1 to the address _cpackbufPtr. This increments the index of packBuf. The next and final instruction in the loop, shr _csamp, #8, shifts the contents of the variable _csamp right by 8 bits (in other words, shifts the low byte out and moves the next higher byte into the low byte position). Finally, the instruction djnz r0, #:s0loop will decrement r0 by 1 and loop to :s0loop if r0≠0.

The first time through the loop, the low byte (bits 0–7) of _csamp is copied to packBuf[0]. The second time (after the increment of _cpackbufPtr and the shift right by 8 bits of _csamp), the second byte (the original bits 8–15 of _csamp) is copied to packBuf[1]. The third time, the third byte of _csamp is copied to packBuf[2]. In the process, _csamp is destroyed—and we note that in the comments for the subroutine so that the calling routine knows not to use _csamp again.

9.3.5 Testing the Compression of Sample 0

Let's run our tests (including running our previous test). If these succeed, we are confident that the array addresses are being passed correctly.

```
Compression
mainCogId:     0
comprCogId:     2
Test that the compression cog sets ncompr => 0
...ok
Test that sample 0 is properly packed to packBuf
...ok
Test that compressor sets ncompr correctly for sample 0
...ok
Test that compressor sets compression code correctly for sample 0
...ok
Tests Run: 4
Tests  Passed:  4
Tests Failed: 0
```

9.4 Packing Differences for Latter Samples

Now that we know how to access the arrays, we can proceed with compressing all the samples by forming differences and packing those differences in packBuf based on their length.

Here is the PASM code in Listing 9-6. Here we add code to handle all the samples and to set the compression codes correctly.

Listing 9-6. Changes to the PASM code to handle all the samples and to set the compression codes correctly

```
...
mov r0, par
add r0, #16
rdlong _ccomprcodebufPtr, r0

mov _cj, #0 ' j-th samp
' there are 16 codes in each code word
' there are NSAMPS_LONG /16 code longs (e.g., 8 codelongs for 128 samps)
' samps 0-15 have their codes in _ccodebufptr [0],
' samps 16 -31 have their codes in _ccodebufptr [1], etc
' _ccodebitidx is the location within a long (0, 2, 4, ... 30)
' _ccodelongidx is the idx of the long in the code array
mov _ccodebitidx, #0
mov _ccodelongidx, #0

call #GET_SAMPLE
mov _cprev, _csamp ' save sample for diff
call #HANDLE_SAMP0
add _ccodebitidx, #2

sub _cns, #1 wz
if_z jmp #:done

```

```
: loopns
   call #GET_SAMPLE
   call #HANDLE_SAMPJ
   mov _cprev, _csamp
   add _cj, #1

   add _ccodebitidx, #2
   test _ccodebitidx, #31 wz
   if_nz jmp #:samelong

   wrlong _ccomprcode, _ccomprcodebufptr
   add _ccomprcodebufptr, #4
   mov _ccomprcode, #0

: samelong
   djnz _cns, #:loopns

:done
  ' wait for another compression request - zero out myns
  ' so we don't immediately start another compression cycle
  wrlong _cns, _cnsPtr
  ' signal completion
  wrlong _cncompr, _cncomprPtr
  jmp #:mainLoop
...
HANDLE_SAMPJ
" form difference between j and j-1 samps
" determine byte - length of diff
" save diff to packbuf
" increment ncompr appropriately
```

```
54  " modify comprcode appropriately
55
56  HANDLE_SAMPJ_ret ret
```

We have added these variables:

- `_cj`: The current sample number.
- `_ccodelongidx`: The index into the array `comprCodeBuf` where the current sample's code will be stored.
- `_ccodebitidx`: The bit location within the long where the code will be stored.
- `_cprev` and `_cdiff`: The previous sample and the difference between the current and previous samples.

After initializing these variables (lines 6–14), we handle the special case of sample 0 (lines 16–18). Here we add the instruction `mov _cprev, _csamp` before the subroutine call `HANDLE_SAMP0`. Remember, that subroutine destroys `_csamp`, so if we want to use it to form the difference, we must save it. Next, we check for whether there is only one sample, and if so, we are done (lines 20–21): subtract 1 from `_cns` (the number of samples) and set the `Z` flag if the result is 0 (that is the effect of `wz`). If `Z` is set, jump to the code to finalize the compression (`done`) when the `myncompr` variables in hub memory are set to the correct values (which signals the main cog that the compression has completed).

If there is more than one sample to process, continue and process those samples in lines 23–38.

- **Lines 24–25**: Get the next sample and process it (we'll look at `HANDLE_SAMPJ` in a moment).
- **Lines 26–27**: Save the sample for the next loop and increment `j`.

- **Lines 29–31**: The bit index moves up by 2, and we check whether we need to move to the next `comprCodeBuf` long. The instruction `test_ccodebitidx, #31 wz` will set `Z` if `ccodebitidx` is equal to `32` (`31=%0001 1111` and `32=%0010 0000`; the bitwise AND of the two numbers is 0, which will set `Z` to 1) The instruction `test` is like `and`, but doesn't save the result; it only affects the flags. If `Z` is not set, then we are still within this `comprCodeBuf` long, and we jump around the subsequent code.
- **Lines 33–35**: New `comprCodeBuf` long. Write the completed long to hub memory and increment the pointer to point to the next long.

OK, now let's look at `HANDLE_SAMPJ`, shown in Listing 9-7. Here we take the difference between the two samples and determine if that number would fit in one, two, or three bytes and handle packBuf and comprCodeBuf accordingly.

Listing 9-7. Subroutine to form the difference between two samples and to update packBuf and comprCodeBuf depending on the size of the difference

```
HANDLE_SAMPJ
" form the difference diff=csamp -cprev
" if |diff| < 127, write 1 byte of diff
" if |diff| < 32767, write 2 bytes of diff
" else write three bytes of diff.
" ccode, ccodebitidx changed
" packbufptr incremented by 1,2, or 3

  mov _cdiff, _csamp
  sub _cdiff, _cprev

  ' write a byte and check if more need to be written
  ' repeat as necessary
  ' r0 - running count of number of bytes used by diff
  ' r1 - compr code - updated as more bytes are used
  ' r2 - abs value of cdiff
  wrbyte _cdiff, _cpackBufptr
  add _cpackBufptr, #1
  mov r0, #1
  mov r1, _ccode08
  ' is -127 < cdiff < 127
  abs r2, _cdiff
  cmp r2, _onebyte wc,wz
  if_c_or_z jmp #:donej

  ' write 2nd byte
  shr _cdiff, #8
  wrbyte _cdiff, _cpackBufptr
  add _cpackBufptr, #1
  add r0, #1
  mov r1, _ccode16
  ' is -32K < cdiff < 32k
  cmp r2, _twobyte wc,wz
  if_c_or_z jmp #:donej

  ' must be 3 bytes long ...
  shr _cdiff, #8
  wrbyte _cdiff, _cpackBufptr
  add _cpackBufptr, #1
  add r0, #1
  mov r1, _ccode24

:donej
  add _cncompr, r0 ' add number of bytes seen here to ncompr
  rol r1, _ccodebitidx
  or _ccode, r1

HANDLE_SAMPJ_ret ret
...
```

```
50  _onebyte long $7F
51  _twobyte long $7F_FF
```

- **Lines 9–10**: Form the difference `diff = samp - prev`.
- **Lines 17–24**: Write the low byte of `diff` to `packBuf` and set the code temporarily to `CODE08`. Check if $||\delta_j|| < 127$: `cmp r2, _onebyte wc,wz`. The constant `_onebyte` is 127, and `wz` says to set `Z` if `r2` is equal to 127; `wc` says to set `C` if `r2` is less than 127. `if_c_or_z jmp #:donej` says to jump to `donej` if `C` or `Z` is set.
- **Lines 26–41**: If `r2` is greater than 127, then write the second byte of `diff`; check again if that is all we need to do. If not, write the third byte of `diff`.
- **Lines 43–46**: `r0` has the number of bytes of diff (1, 2, or 3). Add it to `_cncompr. r1` has the compression code (`CODE08`, `CODE16`, or `CODE24`). Shift it to the correct location (`rol` means "rotate left") and set those two bits of `_ccode` (with an `or` instruction).

9.4.1 Testing Compressing Two Samples!

The following are the tests for the new code to test the code for compression (Listing 9-8). Hopefully the names of the methods and the informational string (in TDD.ASSERT_TRUTHY) are self-explanatory. Each testing method tests a small piece of functionality and should be re-run whenever changes are made to the code.

Listing 9-8. Some of the tests that exercise different parts of the compression code

```
PUB MAIN
...
  TEST_THAT_SAMP1_IS_PROPERLY_PACKED_ONE_BYTE
  TEST_THAT_SAMP1_IS_PROPERLY_PACKED_TWO_BYTES
  TEST_THAT_SAMP1_IS_PROPERLY_PACKED_THREE_BYTES
  TEST_THAT_SAMP1_SETS_COMPRCODE_CORRECTLY
  TEST_THAT_SAMP1_SETS_COMPRCODE_CORRECTLY_TWO_BYTES
...
PRI TEST_THAT_SAMP1_IS_PROPERLY_PACKED_ONE_BYTE | t0, nc, d
  nsamps := 2
  d := 42
  sampsBuf[0] := $AB_CD_EF
  sampsBuf[1] := sampsBuf[0] + d ' diff will be < 127
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, @comprCodeBuf)
  t0 := nc <> -1 & (packBuf[3] == d)
  TDD.ASSERT_TRUTHY (t0, string("Test that sample 1 is properly packed to packBuf (1 byte)"))

PRI TEST_THAT_SAMP1_IS_PROPERLY_PACKED_TWO_BYTES | t0, nc,d
  nsamps := 2
  d := 314
  sampsBuf[0] := $AB_CD_EF
  sampsBuf[1] := sampsBuf[0] + d ' diff will be less < 32k but > 127
  nc :=COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, @comprCodeBuf)
  t0 := nc <> -1 & (packBuf [3] == d & $FF) & (packBuf [4] == d >> 8 & $FF)
  TDD.ASSERT_TRUTHY (t0, string("Test that sample 1 is ➥
  properly packed to packBuf (two bytes)"))

PRI TEST_THAT_SAMP1_SETS_COMPRCODE_CORRECTLY | t0, nc
  nsamps := 2
  sampsBuf[0] := $AB_CD_EF
  sampsBuf[1] := $AB_CD_EF + $42
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ➥
  @comprCodeBuf)
  t0 := nc <> -1 & (comprCodeBuf [1] & %1111 ==
  (COMPR#CODE08 <<2) | (COMPR # CODE24))
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets ➥
  compression code correctly for sample 1"))

PRI TEST_THAT_SAMP1_SETS_COMPRCODE_CORRECTLY_TWO_BYTES | t0, nc
  nsamps := 2
  sampsBuf[0] := $AB_CD_EF
  sampsBuf[1] := $AB_CD_EF + $42_42
  nc :=COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ➥
  @comprCodeBuf)
  t0 := nc <> -1 & (comprCodeBuf [1] & %1111 == (COMPR# ➥
  CODE16 << 2) | (COMPR # CODE24))
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets ➥
  compression code correctly for sample 1 (2 bytes)"))
```

```
Compression
mainCogId: 0
comprCogId: 2
Test that the compression cog sets ncompr => 0
...ok
Test that sample 0 is properly packed to packBuf
...ok
```

```
Test that compressor sets ncompr correctly for sample 0
...ok
Test that compressor sets compression code correctly for sample 0
...ok
Test that sample 1 is properly packed to packBuf (1 byte)
...ok
Test that sample 1 is properly packed to packBuf (two bytes)
...ok
Test that compressor sets compression code correctly for sample 1
...ok
Test that compressor sets compression code correctly for sample 1 ↩
(2 bytes)
...ok

Tests Run: 8
Tests Passed: 8
Tests Failed: 0
```

9.4.2 Test Compressing an Arbitrary Number of Samples

Now that we have tested the cases of two samples being packed correctly, let's see if an arbitrary number of samples are packed correctly. Remember, the compression codes are written two bits at a time; the compression codes for samples 0–15 are stored in `comprCodeBuf[0]` and for sample 16 into `comprCodeBuf[1]`. We need to exercise the code in as many "edge" cases as possible. Here are the most basic ones: 16 samples, 17 samples, and 127 samples. This is not an exhaustive test but will give us some confidence that we are packing the bytes correctly and writing the compression codes correctly. Now that we know that the first and second sample are handled correctly, let's write tests that walk through compressing the whole array, including testing for "edge cases" where problems often occur (Listing 9-9).

Listing 9-9. Testing that more than two samples can be compressed correctly

```
PUB MAIN
...
  TEST_THAT_SAMP15_PACKS_PROPERLY
  TEST_THAT_SAMP16_PACKS_PROPERLY
  TEST_THAT_SAMP127_PACKS_PROPERLY
...
PRI TEST_THAT_SAMP15_PACKS_PROPERLY | t0, nc, i, d
  nsamps := 16
  longfill(@sampsBuf, 0, 16)

  sampsBuf[14] := 12
  d := -42
  sampsBuf[15] := 12 + d
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf)
  repeat i from 0 to nc -1
    UARTS.HEX(DEBUG, packBuf [i], 2)
    UARTS.PUTC(DEBUG, SPACE)

  t0 := nc == 18
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor ↩
  sets nc correctly for samp 15"))
  t0 := comprCodeBuf[0] >> 30 == %01
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor ↩
  sets compr code correctly for samp 15"))
  t0 := packBuf [nc -1] == d & $FF
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor 
  sets compr code correctly for samp 15"))

PRI TEST_THAT_SAMP16_PACKS_PROPERLY | t0, nc, i, d
  nsamps := 17
  longfill(@sampsBuf, 0, 17)

  sampsBuf[15] := 12
  d := -42
  sampsBuf[16] := 12 + d
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, 
  @comprCodeBuf)
  t0 := nc == 19
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets 
  nc correctly for samp 16"))
  t0 := comprCodeBuf[1] & %11 == %01 '
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets 
  compr code correctly for samp 16"))
  t0 := packBuf [nc -1] == d & $FF
  TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets 
  compr code correctly for samp 16"))

PRI TEST_THAT_SAMP127_PACKS_PROPERLY | t0, nc, i, d
  nsamps := 128
  longfill(@sampsBuf, 0, 128)

  sampsBuf[126] := 12
  d := -42
  sampsBuf[127] := 12 + d
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf,
  @comprCodeBuf )
  t0 := nc == 130
```

```
TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets ↩
nc correctly for samp 127"))
t0 := comprCodeBuf[7] >> 30 == %01 '
TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets ↩
compr code correctly for samp 127"))
t0 := packBuf [nc -1] == d & $FF
TDD.ASSERT_TRUTHY (t0, string("Test that compressor sets ↩
compr code correctly for samp 127"))
```

In all these tests, we zero out `sampsBuf` and then set the last two samples to known values. We run the compression and make sure the number of compressed bytes is correct and that the packed array and compression code array have the correct values.

9.5 Success?

Did we speed things up? By how much?

```
nc= 382
dt= 29264
dt (ms) ~ 0
```

The Spin version took 1.5 million clocks, and the PASM version takes 29,000 clocks. This is *a factor of 50 speedup*. (Our original estimate was for 25,000 clocks in the PASM version, so that's not bad.)

Let's do a more comprehensive set of tests by writing a decompressor in the next chapter.

9.6 Summary

In this chapter, we showed how to pass an array to a PASM cog. When a new cog is launched, the address (in the hub) of a variable can be stored in the PAR register, which the new cog can use. To pass arrays, we need another level of indirection! The address at the start of the array is stored in a memory location. The address of that memory location is passed to the PASM cog in PAR (Listing 9-10 has a template that you can modify for new programs). PASM requires that we pay attention to every detail of the computation and build the “scaffolding” of our program from the ground up, much as is shown in Figure 9-6 for a railroad bridge used by Union Army during the Civil War.

Listing 9-10. Template for passing parameters to a PASM cog that uses both methods discussed in this chapter

```
VAR
  long dataArray[100]
  long dataArrayPtr

PUB MAIN
  ' store the address of start of dataArray in dataArrayPtr
  dataArrayPtr := @dataArray
  ' pass the address of dataArrayPtr to the new cog in PAR
  cognew(@MYARRCOG, @dataArrayPtr)

DAT
MYARRCOG org 0
  ' par has the address of dataArrayPtr, which is copied to r0
  mov r0, par
  ' doing a rdlong from that address gets the address of ↩
  the start
```

```
    ' of dataArray
    rdlong _cdataArrPtr, r0

    ' doing a rdlong from _cdataArrPtr gets the first element of dataArray
    rdlong _cdata, _cdataArrPtr
   ...
    ' increment to the next element of dataArray and get it ...
    add _cdataArrPtr, #4
    rdlong _cdata, _dataArrPtr
```

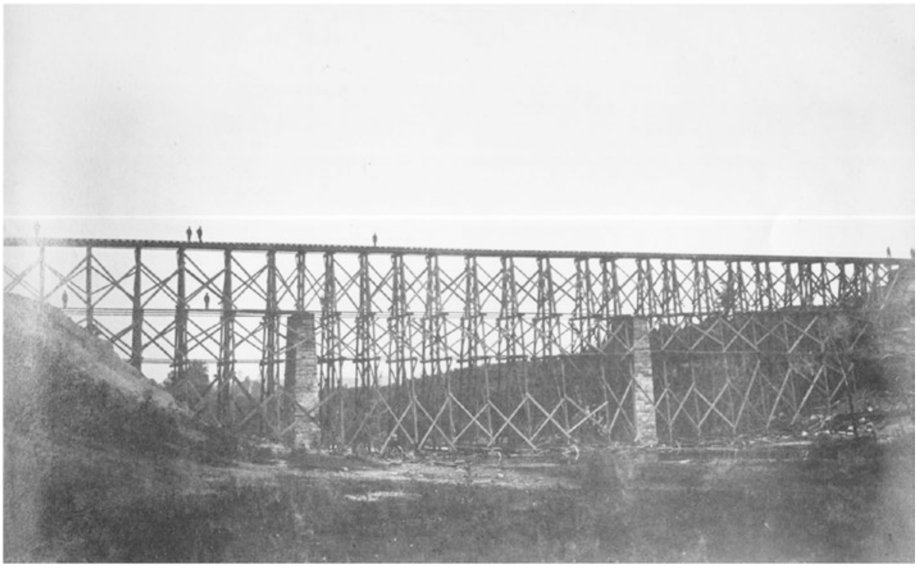


Figure 9-6. *Railroad bridge across Potomac Creek, 1863 or 1864. "That man Haupt has built a bridge across Potomac Creek, about 400 feet long and nearly 100 feet high, over which loaded trains are running every hour and, upon my word, gentlemen, there is nothing in it but beanpoles and cornstalks!" —Abraham Lincoln, May 23, 1862. Library of Congress, ppmsca.11749.*

CHAPTER 10

Decompression in PASM

In this chapter we will write a PASM decompressor. We will go in the opposite direction from the compression code (flowchart in Figure 10-1): converting the `packBuf` array to the `sampsBuf` array (using the `comprCodeBuf` array to help in the reconstruction). In Figure 10-2, we have a great picture demonstrating that what goes up must come down… and that work can be fun!

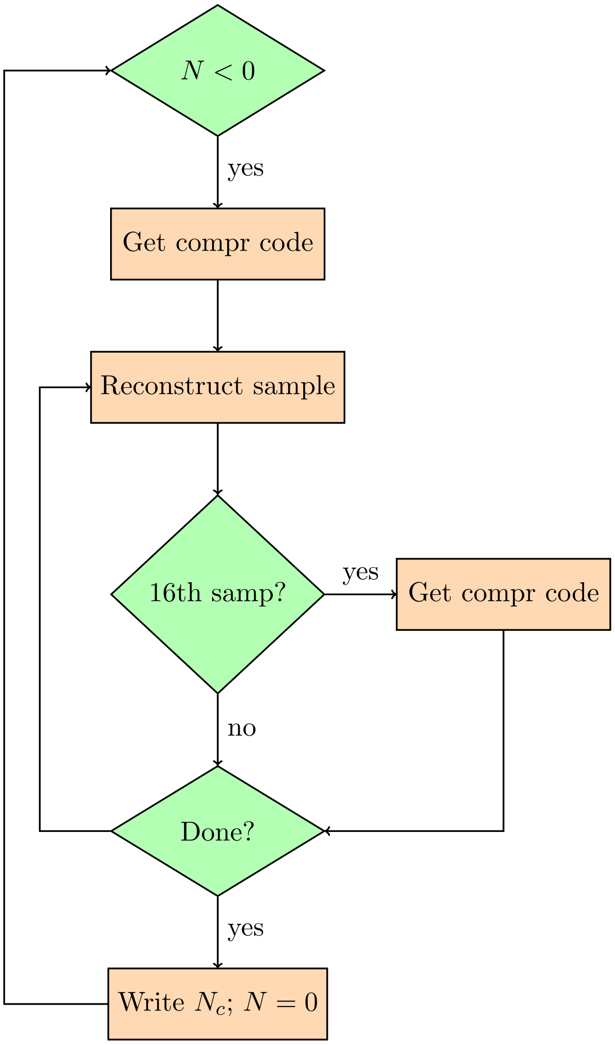


Figure 10-1. *Flowchart for decompression of samples*

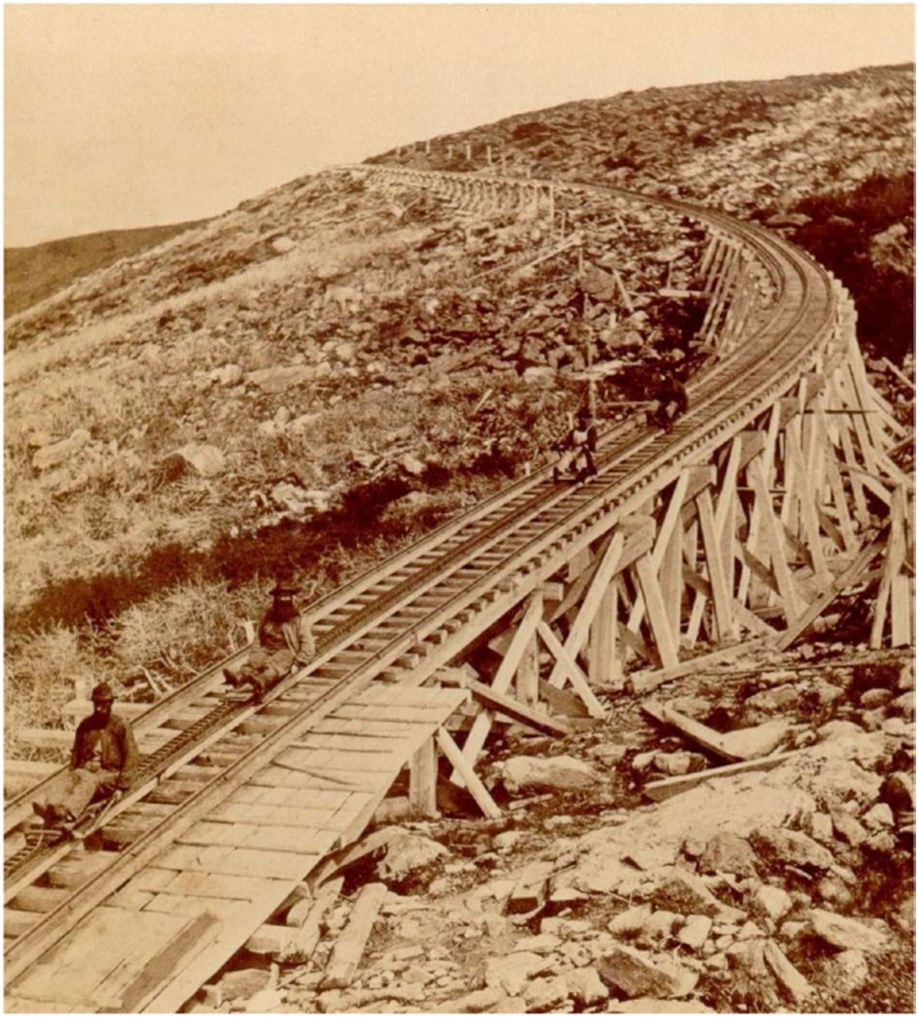


***Figure 10-2.** Riding the cog railway down. Mt. Washington Railway. By Benjamin West Kilburn (1827–1909). Reproduced from an original stereographic card published by Kilburn Brothers, Littleton, New Hampshire, Public Domain, `https://commons.wikimedia.org/w/index.php?curid=20253073`.*

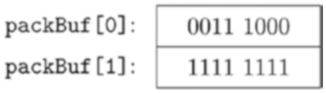
10.1 Getting the Sign Right

Remember, `packBuf` contains sample 0 (the low 3 bytes) and differences between the `j`-th and `j-1` sample. The length of the difference is stored (as 2 bits at the appropriate location) in the long array `comprCodeBuf`.

To regenerate the samples, we need to first get the difference value and make it a proper long. Let's say the difference between two samples was equal to -200, which would be represented as a 2s-complement long:

11111111	11111111	11111111	0011 1000

Because the absolute value of the number is greater than 127, this will be stored in 2 bytes in `packBuf`, as shown here:



packBuf[0]:	0011 1000
packBuf[1]:	1111 1111

To reconstruct the original number, we have to *sign-extend* the high bit of the second byte. If that bit is 1 (as it is here), then we must put 1s in all the bits of the upper 2 bytes as well.

10.2 Overall Flowchart

Figure 10-1 shows the flowchart. We trigger the decompression by setting $N < 0$ (`myns`) to signal the PASM cog that we want decompression rather than compression (recall, for compression, we set $N > 0$).

The cog will read a compression code long and, based on the codes, read the correct number of bytes from `packBuf`. It will then reconstruct a sample. Every 16th sample, it will read a new compression code from hub memory. Finally, after processing all the samples, it will set $N = 0$.

Once the PASM cog completes the decompression, it will set `myns` to zero and set `myncompr` to the number of bytes read from `packBuf` during the decompression. (This can be used as a check on the decompression; it should be equal to `ncompr` from the compression stage.)

10.3 Spin Code

Listing 10-1 shows the Spin code for decompression.

Listing 10-1. Decompression Method in Spin That Triggers the PASM Decompression Cog

```
PUB DECOMPRESS(psampsBuf, ns, ppackBuf, ncompr, pcomprcodeBuf)
" Inputs : psampsBuf - address of long array of samples ↩
(max len mymax)
"          ns - number of samples to decompress
"          ppackBuf - address of byte array of packed data
"          pcomprCodeBuf - address of long array of ↩
           compression codes
" Output : ncompr - number of bytes unpacked from packBuf
" Modified : sampsBuf
  myns := 0
  myncompr := 0

  sampsBufAddr := psampsBuf
  packBufAddr := ppackBuf
  comprCodeBufAddr := pcomprCodeBuf

  ' this will start the decompression
  ' set to negative ns to trigger decompression
```

```
    myns := -ns

    ' when myns is zero, the decompression is complete
    repeat until myns == 0
    return myncompr
```

10.4 PASM: Main Decompression Loop

We will use the same cog as in the previous chapter but will trigger a decompression if `myns < 0` (in the previous chapter, `myns > 0` was a signal to start a compression). See Listing 10-2.

Listing 10-2. Decompression Code in PASM; Initialization

```
    mov _ccodebitidx, #0
    mov _ccodelongidx, #0

' ADD THESE LINES >>>
    ' check for compression or decompression ?
    abs r0, _cns wc ' C set if nsamps < 0
    if_c jmp #:decompress
' ADD THESE LINES <<<

    call #GET_SAMPLE
    mov _cprev, _csamp ' save sample for diff
    call #HANDLE_SAMP0
```

Here we add two lines in the initialization section: `abs r0, cns wc` will take the absolute value of `_cns` and set `C` if `_cns` is negative. If so, jump to `:decompress`.

Listing 10-3 shows the decompression code.

Listing 10-3. Decompression Code in PASM; Details

```
: decompress ' _cns negative

   rdlong _ccomprcode, _ccomprcodebufptr
   mov _cncompr, #0
   mov _cj, #0

   call #MK_SAMP0
   call #PUT_SAMPLE

   add _cj, #1 'sample number j
   add _cns, #1 wz
   if_z jmp #:donedecomp

' and the rest of the samps
: loopdecompns
   call #MK_SAMPJ
   call #PUT_SAMPLE
   add _cj, #1
   add _cns, #1

   ' every 16th sample, read a new comprcode long
   test _cj, #15 wz
   if_nz jmp #:testns
   add _ccomprcodebufptr, #4
   rdlong _ccomprcode, _ccomprcodebufptr

: testns
   tjnz _cns, #:loopdecompns
```

```
29
30  : donedecomp
31     wrlong _cncompr, _cncomprPtr
32     ' signal decompression complete
33     wrlong _cns, _cnsPtr
34     jmp #:mainLoop
```

You should recognize most of the code, explained here:

- **Lines 3–5**: Get the first compression code long and initialize the variables `ncompr` and `j`.
- **Lines 7–8**: Make sample 0 from `packBuf` and write it to `sampsBuf` in the hub (subroutines are explained in the next section).
- **Lines 10–12**: Here we *add* 1 to `_cns` because it starts out at `-ns`. When it is zero, we are done.
- **Lines 15–28**: Loop over the remaining samples.
- **Lines 22–25**: During this loop, every 16th sample, read a new compression code long from hub memory.
- **Lines 28–34**: Once we have processed all the samples, set `myncompr` to the number of bytes read from `packBuf` and set `myns` to zero to signal the completion of decompression.

10.5 Subroutines for Unpacking

Listings 10-4, 10-5 and 10-6 shows the three new subroutines.

Listing 10-4. Decompression Code in PASM; Subroutine to Save a Sample to the Hub After Reconstruction

```
PUT_SAMPLE
' put a sample from _csamp to HUB sampsBuf
  wrlong _csamp, _csampsbufPtr
  add _csampsbufPtr, #4
  PUT_SAMPLE_ret ret
```

PUT_SAMPLE should be obvious: write the reconstructed sample back to hub memory and increment the pointer. See Listing 10-5.

Listing 10-5. Decompression Code in PASM; Subroutine to Reconstruct the First Sample

```
MK_SAMP0 ' decompress samp 0
' read from HUB packbuf to _csamp for samp0 (3 bytes)
    mov r0, #0
    mov _csamp, #0
:read3
    rdbyte r1, _cpackbufPtr
    shl r1, r0
    or _csamp, r1
    add _cpackbufPtr, #1
    add r0, #8
    cmp r0, #24 wz
    if_nz jmp #:read3

    rol _csamp, #8 ' sign extend
    sar _csamp, #8
```

```
16
17      ' update ncompr and code
18      add _cncompr, #3
19      shr _ccomprcode, #2 ' remove samp0 code ...
20      MK_SAMP0_ret ret
```

MK_SAMP0 reads 3 bytes from packBuf and places them in the correct spots in _csamp.

- **Lines 3–4**: r0 is the number of bits to shift each byte of packBuf. r1 is the current byte read from packBuf and shifted by 0, then 8, then 16 bits (bytes 0, 1, and 2, respectively).
- **Lines 5–12**: Loop three times to :read3 (r0 = 0, 8, and 16). When r0==24, break out of the loop. The sign bit for the sample isn't correctly set yet (the upper byte, which is byte 3, containing bits 31–24 are all zero. However, if the sample was originally negative, those bits should all be 1. Luckily, that information (about whether the sample was originally negative or positive) is in the most significant bit of byte 2 (bit 23). If the sample was originally negative before compression, bits 23 would have been 1; if the sample was positive, bit 23 would be 0. The instruction rol _csamp, #8 shifts bits 23–0 up to bits 31–8, and sar _csamp, #8 then shifts the bits back to the right *but preserves the sign of the long*. In other words, we shift bit 23 to bit 31 (rol) and then shift bit 31 back to 23, but if it is a 1, then bits 31–23 are set to 1. If that MSB is a zero, then those bits are set to 0.
- **Lines 18–19**: Update ncompr and comprCode.

Finally, Listing 10-6 shows the reconstruction of the `j`-th sample by properly making the difference and adding it to the previous sample.

Listing 10-6. Decompression Code in PASM; Subroutine to Reconstruct a Sample

```
MK_SAMPJ
    mov r0, #0 ' number of bytes
    mov _cdiff, #0
    mov r1, _ccomprcode
    and r1, #3 ' get compr code for this samp. (2 low bits)
    shr _ccomprcode, #2 ' and prep for next loop ...

    ' byte 0 - right most
    rdbyte r2, _cpackbufPtr
    add _cpackbufPtr, #1
    mov _cdiff, r2
    add r0, #1
    cmp r1, _ccode08 wz ' check r1 (code)

    if_z jmp #:shiftde

    ' byte 1
    rdbyte r2, _cpackbufPtr
    add _cpackbufPtr, #1
    rol r2, #8
    or _cdiff, r2
    add r0, #1

    cmp r1, _ccode16 wz
    if_z jmp #:shiftde

    ' byte 2
    rdbyte r2, _cpackbufPtr
    add _cpackbufPtr, #1
    rol r2, #16
    or _cdiff, r2
    add r0, #1

: shiftde
     ' set the sign of the diff correctly by sign extending ...
     ' 1 byte diff ...
     cmp r0, #1 wz
     if_nz jmp #:sh2
     rol _cdiff, #24 ' sign extend
     sar _cdiff, #24
     jmp #:donede

     ' 2 byte diff ...
:sh2
     cmp r0, #2 wz
     if_nz jmp #:sh3
     rol _cdiff, #16 ' sign extend
     sar _cdiff, #16
     jmp #:donede

     ' 3 byte diff ...
:sh3
     rol _cdiff, #8 ' sign extend
     sar _cdiff, #8

: donede
```

```
57        ' add sample to prev
58        add _csamp, _cdiff
59        ' now mask off the high byte and sign extend the 3 lower
60       rol _csamp, #8
61       sar _csamp, #8
62       add _cncompr, r0 ' update ncompr
63   MK_SAMPJ_ret ret
```

MK SAMPJ tests the value of the compression code for the j-th sample and reads 1, 2, or 3 bytes from packBuf accordingly. It writes those bytes to _cdiff (with the dance of shifting left and right to get the sign right) and then adds _cdiff to _csamp to get the current sample (again, with the shift left/right dance).

- **Lines 2–6**: Initialize variables. r0 is number of bytes to read, r1 is the compression code, and r2 will be the byte read from packBuf.
- **Lines 9–15**: Read a byte, place it in _cdiff, and check the code to see whether we are done.
- **Lines 13–25**: If code was CODE08, then we're done. If not, then get another byte, shift it left by 8, and or it with _cdiff.
- **Lines 28–32**: Again, these lines will properly set byte 2 if necessary (if the compression code is CODE16).
- **Lines 34–54**: If only 1 byte was read (r0==1), then shift _cdiff by 24 bits up and then back down. If 2 bytes were read, then shift by 16; if 3 were read, then shift by 8; and so on.
- **Lines 58–62**: Add _cdiff to _csamp (the previous sample), shift it up by 8, and then shift it back down and return.

10.6 Testing Decompression of Two Samples

The testing is straightforward: compress the samples and then decompress them. In between the compression and decompression, I set sampsBuf to zero, so I know that the values in sampsBuf after decompression were in fact generated by the decompression code. Compare these values for sampsBuf with the original numbers.

```
PUB MAIN
...
  TEST_THAT_SAMP0_IS_PROPERLY_UNPACKED
  TEST_THAT_SAMP1_IS_PROPERLY_UNPACKED
...
PRI TEST_THAT_SAMP0_IS_PROPERLY_UNPACKED | t0, nc, nc1, ns, d
  nsamps := 1
  d := $FF_FF_AB_CD
  sampsBuf[0] := d
  nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  @comprCodeBuf)
  sampsBuf[0] := 0

  nc1 := COMPR.DECOMPRESS (@sampsBuf, nsamps, @packBuf, ↩
  nc, @comprCodeBuf)

  t0 := (nc == nc1) & (sampsBuf[0] == d)
  TDD.ASSERT_TRUTHY (t0, string (" Test that sample 0 is ↩
  properly unpacked from packBuf "))

  PRI TEST_THAT_SAMP1_IS_PROPERLY_UNPACKED | t0, nc, nc1, ↩
  ns, s0, s1
```

```
nsamps := 2
s0 := $FF_FA_09_19
s1 := $FF_FA_4F_2E
sampsBuf[0] := s0
sampsBuf[1] := s1
nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
@comprCodeBuf)
sampsBuf[0] := 0
sampsBuf[1] := 0

nc1 := COMPR.DECOMPRESS (@sampsBuf, nsamps, @packBuf, nc, ↩
@comprCodeBuf)
t0 := (nc == nc1) & (sampsBuf[1] == s1)
TDD.ASSERT_TRUTHY (t0, string(" Test that sample 1 is ↩
properly unpacked from packBuf "))
```

The test should pass, as shown here:

```
Test that sample 0 is properly unpacked from packBuf
...ok
Test that sample 1 is properly unpacked from packBuf
...ok
```

10.7 Testing Decompression of 128 Samples

OK, that worked. Let's try it with 128 samples. We will generate 128 pseudorandom numbers. Listing 10-7 shows the Spin instructions.

Listing 10-7. Testing the Decompression Code; 128 Samples Initialized

```
j := 0
sampsBuf[j] := cnt ' seed it with counter
?sampsBuf[j] ' pseudorandom number
sampsBuf[j] &= $FF_FF_FF ' low 3 bytes only

sampsBuf[j] <<= 8 ' sign extend
sampsBuf[j] ~>= 8
sav[j] := sampsBuf[j]
```

These instructions will seed the sample with the current value of the counter and then use that seed to look up a pseudorandom number. The number has to be limited to 3 bytes, so we mask off those 3 bytes and then sign-extend the upper bit.

The compression, decompression, and testing are done as shown in Listing 10-8.

Listing 10-8. Testing the Decompression Code; Stub Showing Test Results

```
nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
@comprCodeBuf)

repeat j from 0 to nsamps -1
  sampsBuf[j] := 0

  nc1 := COMPR.DECOMPRESS (@sampsBuf, nsamps, @packBuf, nc, ↩
  @comprCodeBuf)

  t0 := (nc == nc1)
  repeat j from 0 to nsamps -1
      t1 := (sampsBuf[j] == sav[j])
      t0 &= t1
```

The samples are compressed, the sampsBuf array is cleared, and the samples are decompressed. We then check that the number of compressed and decompressed bytes is equal (nc==nc1) and that the samples are equal to their saved values.

```
PUB MAIN
...
  TEST_THAT_128_SAMPS_PROPERLY_COMPRESS_AND_DECOMPRESS
...
PRI TEST_THAT_128_SAMPS_PROPERLY_COMPRESS_AND_DECOMPRESS | ↩
t0, t1, j, nc, nc1, sav [128]
    nsamps := 128

    j := 0
    sampsBuf[j] := cnt ' seed it with counter
    ?sampsBuf[j] ' pseudorandom number
    sampsBuf[j] &= $FF_FF_FF ' low 3 bytes only

    sampsBuf[j] <<= 8 ' sign extend
    sampsBuf[j] ~>= 8
    sav[j] := sampsBuf[j]

  repeat j from 1 to nsamps -1
```

```
    sampsBuf[j] := sampsBuf[j -1]
    ?sampsBuf[j] ' pseudorandom numbers
    sampsBuf[j] &= $FF_FF_FF ' low 3 bytes only
    sampsBuf[j] <<= 8 ' sign extend
    sampsBuf[j] ~>= 8
    sav[j] := sampsBuf[j]

nc := COMPR.COMPRESS (@sampsBuf, nsamps, @packBuf, ↩
@comprCodeBuf)

repeat j from 0 to nsamps -1
  sampsBuf[j] := 0

nc1 := COMPR.DECOMPRESS (@sampsBuf, nsamps, @packBuf, nc,↩
 @comprCodeBuf)

t0 := (nc == nc1)
repeat j from 0 to nsamps -1
    t1 := (sampsBuf[j] == sav[j])
    t0 &= t1

TDD.ASSERT_TRUTHY (t0, string(" Test that compression ↩
and decompression of 128 random numbers is successful "))
```

Next run the test, as shown here:

```
Test that compression and decompression of 128 random numbers
is successful
***FAIL
```

Oh no! What went wrong? Let's do some debugging in the next chapter. As you can see in Figure 10-3, there are real-world consequences to engineering or user mistakes!

Figure 10-3. *Derailment at Eastwood Junction, 1948.* *https://upload.wikimedia.org/wikipedia/commons/4/4a/Derailment_at_Eastwood%2C_1948_%285247093755%29.jpg.*

CHAPTER 11

Debugging PASM Code

It is relatively straightforward to debug Spin code. You can insert commands to print the value of variables to the terminal. This is a time-honored way to debug code, and though tedious, it works. In Listings 11-1 and 11-2, I show how I monitor the value of a variable.

Listing 11-1. Debugging Spin Code with Print Commands

```
PUB MAIN
...
  UARTS.STR(DEBUG, string(" nsamps = "))
  UARTS.DEC(DEBUG, nsamps)
  UARTS.PUTC(DEBUG, CR)
```

Insert print statements like this in your Spin code, and you can examine the value of variables at different places.

I find that the verbose set of commands gets inconvenient, so I have defined a method called `PRINTF`.

Listing 11-2. Convenience Method to Print Out a Variable's Value

```

PUB MAIN
...
  PRINTF(DEBUG, string(" nc "), nc, 1)
...
'
' Convenience method to print `n' to port `p' with the ↩
following format :
' PRINTF(DEBUG, string(" nc "), nc, 1)
' nc :3, 0x03, 0 b0000011
PRI PRINTF(p, lbl, n, len)
' p is the serial port, lbl is the string label
' n is the number to print
' len is the number of bytes to display in the hex and binary
    UARTS.STR(p, lbl)
    UARTS.PUTC(p, COLON)
    UARTS.DEC(p, n)
    UARTS.STR(p, string(COMMA, " 0x"))
    UARTS.HEX(p, n, len *2)
    UARTS.STR(p, string(COMMA, " 0b"))
    UARTS.BIN(p, n, len *8)
    UARTS.PUTC(p, CR)
    UARTS.PUTC(p, LF)
```

We can't do the same in PASM code, though. There isn't a simple way to print to the terminal from PASM code, so I will demonstrate two different methods for examining variable values in PASM. These methods of debugging are referred to as logging (see Figure 11-1 for another example of logging; the size of those logs is astonishing and the sight of them cut down is quite sad!)

Figure 11-1. *Redwood logs on train from forest to mill. https://upload.wikimedia.org/wikipedia/commons/9/9a/Redwood_Logging_Train.jpg.*

11.1 Logging to a Hub Array

The first logging technique is to save values to a hub array that can be printed out at leisure. The second is to write a long from one cog to another (from a PASM cog to a Spin cog) using a set of hardware pins and Serial Peripheral Interface (SPI). Here I will look at the first technique. We already looked at the SPI logging in Chapter 7.

1. We will define a new array in Spin called `logBuf`.
2. We will define a new variable in the PASM code called `clogBufPtr`.
3. Before the cog is launched, we will place the address of `logBuf` into `clogBufPtr`.

Recall from Chapter 6 that there are two ways to pass parameters to a PASM cog: by using the `cognew` command and by storing the parameter in the cog code before it is launched. We are using the second method in Listing 11-3.

Listing 11-3. Debugging PASM Code by Passing the Address of the Log Buffer in a Register

```
CON
  LOGLEN = 256

VAR
  logBuf[LOGLEN]

PUB START
  _clogBufPtr := @logBuf
  ccogid := cognew(@STEIM, @myns)
...

DAT 'pasm cog
STEIM ORG 0

... instructions
  rdlong _cns _cnsPtr wz

... variables
_ccode24 long CODE24

_clogBufPtr long 0

... reserved space
_cnsPtr res 1

FIT 496
... system registers (PAR, CNT, etc)
```

We can now write to logBuf from PASM, and the Spin code can print out those values. There is one important caveat: the PASM code and the Spin code run at very different speeds. The PASM code will populate the logBuf array, and at some later time, the Spin code will print it out. For that reason, you should include a label during logging. This label will be some unique identifier that tells you where the log value was written, during which iteration of the loop, and so on.

11.2 Spin Code

Add the following to steim_pasm.spin:

```
CON
  LOGLEN = 256
...
VAR
  byte logIdx

  long logBuf[LOGLEN]

PUB GETLOG
'' return address of log array
  return @logBuf

PUB GETLOGLEN
'' return length of log
  return logIdx
```

Here we define a new array where the log values will be stored, as well as new methods GETLOG and GETLOGLEN that return the address and populated length of that array.

In the main Spin file steim_pasm_Demo.spin, you can use the code in Listing 11-4 to print out the contents of the log array.

Listing 11-4. Debugging PASM Code by Sharing a Log Buffer; Spin Code

```
VAR
  byte loglen
  long logBufPtr

PUB MAIN
...

logBufPtr := COMPR.GETLOG
loglen := COMPR.GETLOGLEN
repeat j from 0 to loglen -1
  UARTS.HEX(DEBUG, long [logBufPtr][j], 8)
```

11.3 PASM Code

Populating the log array is done with wrlong instructions in PASM. The hub address of the log array is available in _clogBufPtr. We first save that value to _clogBufPtrSav so that we can reset to that location when we reach the end of the array.

In Listing 11-5, we implement the logging code. In addition to the storage for the logged data itself, we define a variable _clogIdx and a constant _clogMaxIdx. Every time we write to the log array, we increment the former; when the index reaches the end of the array, we reset the index to the beginning of the array.

Listing 11-5. Debugging PASM Code by Sharing a Log Buffer; PASM Code

```

mov r0, par
add r0, #16
rdlong _ccomprcodebufPtr, r0

''>>> ADD THIS TO INITIALIZATION SECTION OF PASM CODE
  call #INIT_LOG
''<<<
  mov _cj, #0 ' j-th samp

''>>> ADD THESE SUBROUTINE DEFENITIONS
INIT_LOG
  mov _clogIdx, #0
  mov _clogBufPtr, _clogBufPtrSav
INIT_LOG_ret ret

LOG
'' write logVal to logBuf
'' increment logIdx
'' treat as circular buffer
  wrlong _clogVal, _clogBufPtr
  add _clogBufPtr, #4
  add _clogIdx, #1
  wrlong _clogIdx, _clogIdxPtr

  ' wrap around ?
  test _clogIdx, _clogMaxIdx wz
  if_nz jmp #:logdone

  mov _clogIdx, #0
  mov _clogBufPtr, _clogBufPtrSav
:logdone
LOG_ret ret

...

''>>> ADD THESE VARIABLE DECLARATIONS
_clogMaxIdx long LOGLEN -1 ' 0 to loglen -1
_clogIdx long 0
_clogVal long 0

_clogBufPtr long 0
_clogBufPtrSav long 0
...
```

The LOG subroutine keeps track of the index into the log array and resets to the start when it reaches the end. It writes the value in _clogVal to the current address in the log array, increments that address, and resets the address to the beginning of the array if needed.

11.4 Bug Fix

The failure at the end of the previous chapter can now be tracked down. By placing the following statements at strategic places, I discovered that I had made a mistake in writing the compression code longs:

```
mov _clogVal, xxx
call #LOG
```

When there are 128 samples, the compression code array is 8 longs in length (2 bits per sample). However, I was mistakenly writing *a ninth* long, which overwrote memory of another array. (As it turns out, this was the `packBuf` array, but it could have been anything.)

Figure 11-2 shows the compression flowchart again, but I have added a check to the right of “16th samp?” shape. If this is also the last sample, jump out of the loop and finalize.

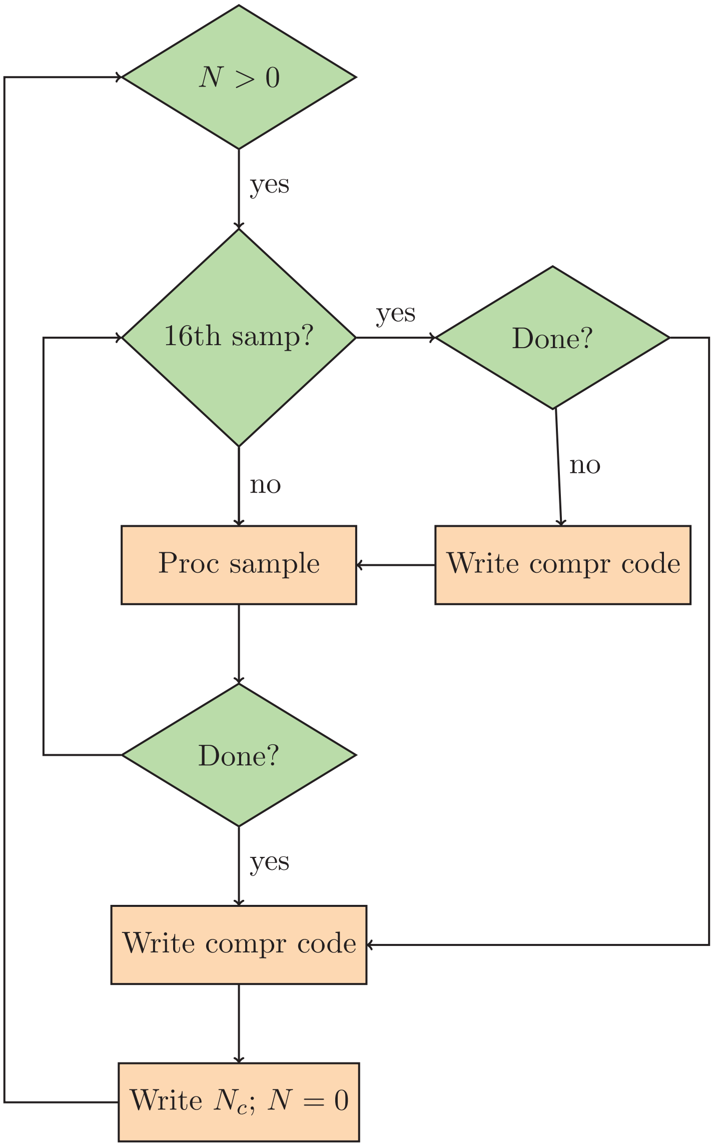


***Figure 11-2.** Flowchart for processing samples, with addition of a check for the final sample before writing the compression code. Compare this figure to Figure 9-1.*

If, for example, there are exactly 16 samples to compress, the compression code is *written only once*.

On the first sample to the 15th sample, control flows down from "16th samp?" to "Done?" and then back up to "16th samp?"

On the last sample, the "16th samp?" query is true, so we go to the right, but the "Done?" query is also true, so we exit the loop and write the compression code at the end (without that question, we would write the compression code twice). In Figure 11-3, we show the consequences of over-running ones bounds!

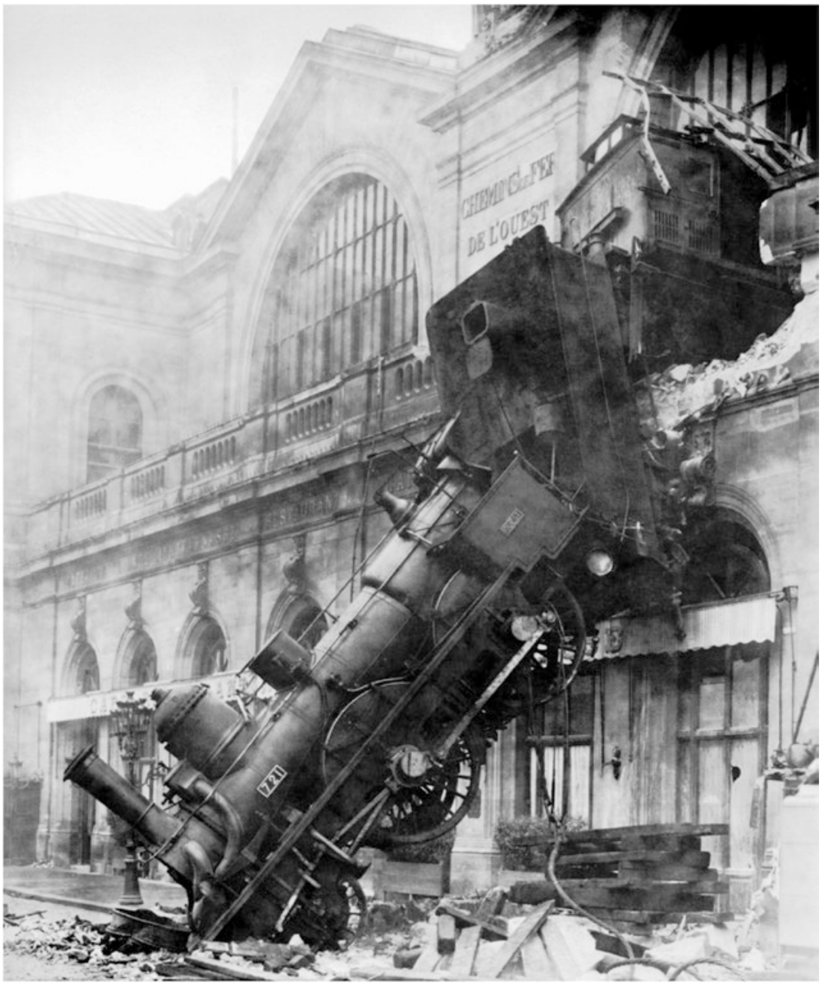


***Figure 11-3.** Train wreck at Gare Montparnasse, Paris, 1895. The train entered the station at a dangerously fast 40–60km/hr, and when the air brake on the locomotive failed, the train crossed the entire concourse (100m) and crashed through a 60cm thick wall before falling to the street below.*

PASM code will allow you modify *any* memory location. There is no checking of array lengths or bounds. It's all up to you!

PART III

C Language

CHAPTER 12

C Programming for the Propeller

Parallax and the community have put enormous effort into bringing a C compiler to the Propeller. The advantage to using C is that it is a stable, established language with a large knowledge base. In addition, there are hundreds of books and web sites devoted to teaching C, and you can use many libraries and pieces of example code in your programs. Many of the programs that run the backbone (or the engine, Figure 12-1) of the Internet are written in C.

***Figure 12-1.** In the engineer's cab on the Chicago and Northwestern Railroad. Photographer Jack Delano, Library of Congress, Farm Security Administration archives (`https://goo.gl/pHmY5t`).*

12.1 The C Language

This section is a short primer on C. I encourage you to get a copy of *The C Programming Language* by Brian Kernighan and Dennis Ritchie, which is the authoritative guide to C. Here are a few important rules to remember:

- C is case sensitive.
- Statements must end with a semicolon (;).
- Blocks are enclosed in paired curly braces (indentation is not important).

```
while (x < 100) {
  x += 1;
}
```

- Block comments have /* at the beginning and */ at the end. Line comments start with //.
- Variable naming follows the same rules as in Spin.
- Numbers are in decimal if naked, hexadecimal if preceded by 0x, and binary if preceded by b.

```
/* a block comment
 * three assignments that do the same thing
 */
x = 42; // decimal . This is a line comment
x = 0x2A; // hex
x = b00101010; // binary
```

Here are some Spin and C parallels:

- **CON**: The equivalent of the CON block in Spin is the #define statement, as shown in Listing 12-1.

Listing 12-1. define Statements in C

```
#define NSAMPS_MAX 128
```

OBJ: The equivalent of the `OBJ` block in Spin is the `#include` statement, as shown in Listing 12-2.

Listing 12-2. #include Statements in C

```
#include <stdio.h>
#include <propeller.h>
```

VAR: Variables can be defined as either *local* variables that are available only within a function or as *global* variables that are available to all functions in the program. To define (reserve space for) a variable, do the following:

```
int nsamps, ncompr;
char packBuf[512];
unsigned int spiSem;
```

Variable definitions are either for individuals (`nsamps`, etc.) or for arrays (`packBuf[512]`). The type of the variable precedes its name. Variables types are the integers `char`, `short`, `int` (8-, 16-, and 32-bit, respectively), and a 32-bit `float`. The integer types can be either `signed` or `unsigned`.

Assignment and math: These are similar to Spin but use an equal sign instead of :=. Addition, multiplication, and division are the same as in Spin. The modulo operator is the percent sign (%).

```
int x, y, z;
x = 12;
x += 42;
y = x/5;   // integer division
z = x % 5; // remainder of x/5
z = x++;   // post - increment: increment x, and store in z
z = ++x;   // pre - increment: store x in z, then increment x
```

Relational and logical operators: These are similar to Spin, but with these differences:

- The *not equal* operator is `!=`.
- The `AND` operator is `&&` and the `OR` operator is `||`.
- The `NOT` operator is `!`.
- The "*less-than-or-equal* and "*greater-than-or-equal*" relations are <= and >=."

In conditional statements, `0` (zero) is false, and any nonzero value is true.

Flow control: There are four flow control statements.

- This is a `for` loop:

```
/* for (<init >; <end condition >; <per - loop action >)
 * The most common for - loop runs N times
 * number of times as below.
 * An infinite loop is for (;;) { <stmts > }.
 * (you can have blank init, end or per - loop)
 */
for(i=0; i<N; i++) {
  x++;
  y--;
}
```

- These are `while` and `do...while`:

```
// while loop. The block only runs if the relation is true.
while (x < 100) {
  y++;
}
// do ... while loop. The block always runs once
// and then check the relation.
```

```
do {
  y++
} while (x < 100);
```

- This is a `switch...case`:

```
switch(menuItems) {
case MENUITEM0:    // if menuItems == MENUITEM0,
  do_menu0();      // execute block up to the break.
  break;
  /*** DANGER **
   * you must have a break at the end
   * of the case block.
   * the break will return control to the switch.
   * without the break, control will pass to the
   * next case block.
   *** YOU WERE WARNED **
   */
case MENUITEM1:
  do_menu1();
  break;
default: // you can include a case that handles
         // unknown values
  handle_unknownMenu();
}
```

Pointers and arrays: Every variable and array has a memory address. The address of variables is given thusly:

```
int x;
/* this defines a pointer to an int */
int *px;
```

```
x = 42;

/* this obtains the address of x and stores it in px */
px = &x;

/* this obtains the value stored at the location
   pointed to by px */
y = *px; // now y is 42
```

Arrays are stored in contiguous memory, and the address of the array is the address of the first element of the array.

```
int sampsBuf[128];
int packBuf[512];

// arrays are zero -based, sampsBuf[0]... sampsBuf[127]
y = sampsBuf[12];

// the memory address of an array is obtained by
// referring to the array.
// the n-th element of the array is obtained by
// adding n to the address, treating that as a pointer
// here we get the 12 th element (12 th int) of sampsBuf
y = *(sampsBuf +12);

// the compiler knows that packbuf is a char array
// so packBuf +12 refers to the 12 th element (12 th byte),
// in this case
z = *(packBuf +12);
```

Pointer arithmetic is needed when you want to modify the value of variables in a function.

```
...
int main() {
  int x = 42;
  int y;
  int *px = &x;
  y = incrementNum(x);
  // x is still 42, but y is 43.
  incrementNumPtr (px);
  // x is now 43.
}

/* incrementNum - increment a variable
 * args: n - variable to be incremented
 * return: incremented value
 */
int incrementNum(int n) { // n is a local copy of x. x is ↩
unaffected.
  return (n++);
}

/* incrementNumPtr - increment the value of a variable.
 * args: *pn - a pointer to an int
 * return: none
 * effect: the variable pointed to by pn is incremented
 */
void incrementNumPtr(int *pn) {
  // pn is a pointer to the int, and *pn is the int itself
  *pn++; // * binds tightly, so parens (* pn)++ not needed.
}
```

12.2 Programming the Propeller in C

To program the Propeller with C code, we have to recognize a few constraints of the device. The first, and most critical, is that hub memory is limited to 32KB and that cog RAM is limited to 2KB. Next, the Propeller has eight cogs, and the C compiler and linker have to handle launching new cogs properly. In this book, I will discuss three cases (cases that I think cover most of the likely projects).

SimpleIDE creates a *workspace* when you first install it. If you have downloaded the repository from `https://github.com/sanandak/propbook-code.git`, then there is a SimpleIDE workspace in `propbook-code`. Select Tools ➤ Properties and set the workspace to the downloaded directory (`.../propbook-code/SimpleIDE`).

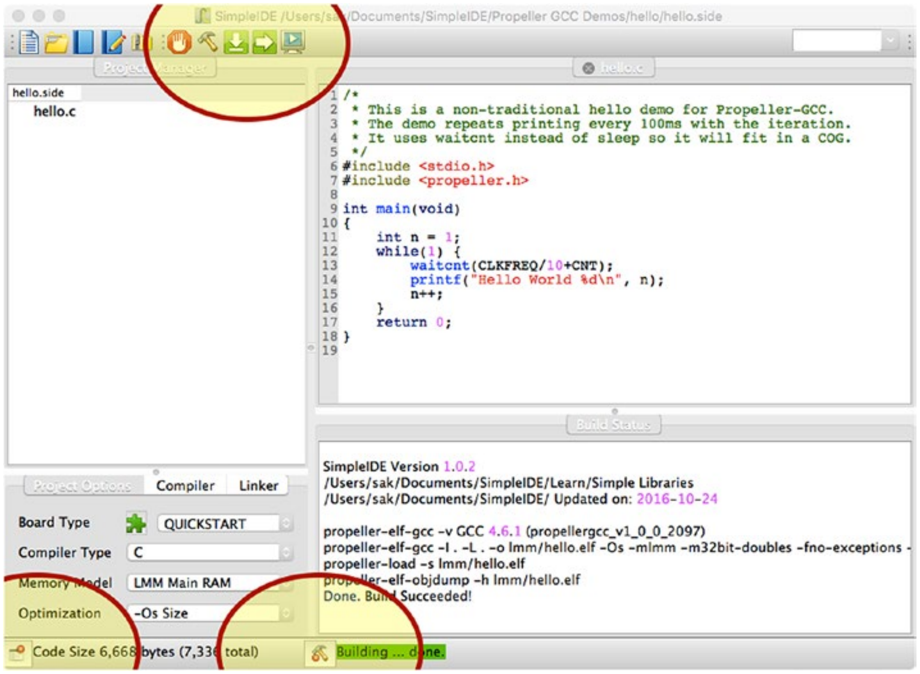
- If the size of the C program (after compiling) is less than approximately 30KB, then it will fit entirely in hub memory. The compiler will place your code into hub along with a *kernel* (approximately sized 2KB, for a total size of less than 32KB). The kernel is a program that copies instructions from your code into a cog and executes them. This is known as the *large memory model* (LMM). The main drawback of LMM is that every instruction resides in the hub and is copied to cog memory before execution, slowing down the program. In almost every way, though, this is a standard C program. Cogs can be launched and stopped; the counters and special registers like `ina` and `outa` can be read and set; the locks can be used; and so on.

- If there is a need for a faster speed from some part of the program, we can place that C code in a Cog-C file (with the extension `.cogc`). This part of the code must compile to assembly code that is less than 2KB in size, and it will be placed into cog RAM and run at full speed. The rest of the program will continue to operate under LMM mode. I call this the *mixed-mode Cog-C model*. The advantage is that the program will run at full speed. The drawback is that the assembly code produced by the compiler may not be as efficient as code that you write.
- The final model is where the speed-critical code is written in PASM and is saved on a cog. This cog is now fully under your control. You can optimize it for your needs (of course, as with the previous case, the code has to be less than 2KB in size). The rest of the code continues to run under LMM. This is called the *mixed-mode PASM model.*

12.2.1 SimpleIDE

To write the code, compile and link it, download it to the Propeller, and view the output, we will use the SimpleIDE application, which is an integrated development environment (IDE). This is a cross-platform IDE (Windows, Linux, and macOS) that is aware of all three of the models and does the detailed work of compiling the programs correctly and linking them in the right way.

The place to start with SimpleIDE is at `http://learn.propeller.com` where you can download the program and step through a series of excellent tutorials on using the program and developing LMM projects (see Figure 12-2).



```
/*
 * This is a non-traditional hello demo for Propeller-GCC.
 * The demo repeats printing every 100ms with the iteration.
 * It uses waitcnt instead of sleep so it will fit in a COG.
 */
#include <stdio.h>
#include <propeller.h>

int main(void)
{
    int n = 1;
    while(1) {
        waitcnt(CLKFREQ/10+CNT);
        printf("Hello World %d\n", n);
        n++;
    }
    return 0;
}
```

```
SimpleIDE Version 1.0.2
/Users/sak/Documents/SimpleIDE/Learn/Simple Libraries
/Users/sak/Documents/SimpleIDE/ Updated on: 2016-10-24

propeller-elf-gcc -v GCC 4.6.1 (propellergcc_v1_0_0_2097)
propeller-elf-gcc -I . -L . -o lmm/hello.elf -Os -mlmm -m32bit-doubles -fno-exceptions -
propeller-load -s lmm/hello.elf
propeller-elf-objdump -h lmm/hello.elf
Done. Build Succeeded!
```

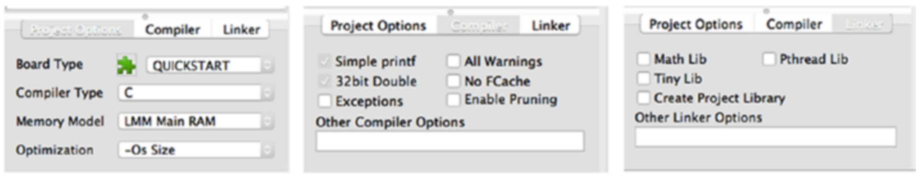
Board Type: QUICKSTART
Compiler Type: C
Memory Model: LMM Main RAM
Optimization: -Os Size

Code Size 6,668 bytes (7,336 total)

Building ... done.

***Figure 12-2.** SimpleIDE window with Project Manager button, Build Window button (at bottom of picture), and Build button (the hammer at the top of the picture) highlighted*

There are three tabs in the Project Manager: the Project Options tab, the Compiler tab, and the Linker tab. The settings shown in Figure 12-3 are good for the examples in this book, so make sure you set yours properly.



Board Type: QUICKSTART
Compiler Type: C
Memory Model: LMM Main RAM
Optimization: -Os Size

✓ Simple printf
✓ 32bit Double
☐ Exceptions
☐ All Warnings
☐ No FCache
☐ Enable Pruning
Other Compiler Options

☐ Math Lib
☐ Tiny Lib
☐ Create Project Library
☐ Pthread Lib
Other Linker Options

***Figure 12-3.** Settings for the Project Options, Compiler, and Linker tabs*

12.2.2 Hello World

After installing SimpleIDE, you will have a number of examples in the `Propeller GCC Demos` folder (in the SimpleIDE workspace). One of those is called `Welcome`. Open the project file `Welcome.side` and build it; you should see messages in the build window ending with "Build Succeeded!" At the bottom of the window a message shows the size of the program (in this case, about 7KB). If the program successfully builds, you can download and run it on the Propeller and have the output displayed on a terminal by clicking the icon at the top that shows a screen with an arrow.

I have modified the code slightly, but it is very straightforward, as shown in Listing 12-3.

Listing 12-3. Hello World Program in C (SimpleIDE/My Projects/ch11/Welcome.c)

```
 1  # include <stdio.h>
 2  # include <propeller.h>
 3
 4  int main(void) {
 5      int n = 1;
 6      while (1) {
 7          waitcnt(CLKFREQ/10 + CNT);
 8          printf(" Hello World %d\n", n);
 9          n++;
10      }
11      return 0;
12  }
```

Lines 1–2: The `stdio` library has the `printf` function. However, because it is a complex (and large) function, the Compiler tab includes the option to use a "Simple printf" that reduces the size somewhat. The `propeller` library has the Propeller-specific functions such as `waitcnt` and `waitpeq` and the special registers such as `CNT`, `INA`, and so on.

Lines 4–13: The main program is similar to the PUB MAIN method in Spin. This function shouldn't exit; it should initialize some variables and then enter an infinite loop.

Line 5: Define the variable n and initialize it to 1.

Line 6: Enter an infinite loop.

Line 7: waitcnt is similar to the waitcnt in Spin, but it has only one argument. The processor will pause at this line until the counter value is equal to the argument of waitcnt. In this case, this is the current count value plus 1 second. The variable CLKFREQ contains the number of counts in 1 second (generally 80 million at top speed, but it depends on the external crystal and the phase-locked loop value).

Line 8: The printf function prints a formatted string to the terminal. Look at the manual page for printf for how to format numbers. In short, %d prints a decimal number, %x prints the number in hexadecimal format, and %f prints a floating-point value.

Line 9: Increment the value of n.

Running the program will result in the following in the terminal window with a new message every tenth of a second:

```
Hello World 1
Hello World 2
Hello World 3
...
```

12.2.3 Launching a New Cog

To launch a new cog in LMM, we must define a function and then pass that function to the cogstart function.

Start a new C project (Open ➤ New) named compr_cog0. Set the Project Options, Compiler, and Linker options as before.

For the purposes of display and discussion, I have split the file `compr_cog0.c` into three separate parts, but really all three parts are in one file. Every multicog program will have these three parts.

Part 1 in Listing 12-4 is the front matter where the libraries are included, the shared memory for the *stack* and the shared variables is set aside, and the constants are defined.

Listing 12-4. Part 1: Front Matter for File compr_cog0.c

```
/*
  compr - cog0.c - start a new cog to perform compression.
*/

/* libraries */
# include <stdio.h>
# include <propeller.h>

/* defines */

// size of stack in bytes
# define STACK_SIZE_BYTES 200
// compression constants
# define NSAMPS_MAX 128
# define CODE08 0b01
# define CODE16 0b10
# define CODE24 0b11
# define TWO_BYTES 0x7F // any diff values greater than ↩
this are 2 bytes
# define THREE_BYTES 0 x7FF // diff values greater than ↩
this are 3 bytes


```

```
22  /* global variables */
23  // reserved space to be passed to cogstart
24  static unsigned int comprCogStack[STACK_SIZE_BYTES >> 2];
25
26  // shared vars
27  volatile int nsamps;
28  volatile int ncompr;
29  volatile int sampsBuf[NSAMPS_MAX];
30  volatile char packBuf[NSAMPS_MAX <<2]; // 128 * 4
31  volatile int comprCodesBuf[NSAMPS_MAX >>4]; // 128 / 16
```

Line 12: The stack is a region of memory used by the kernel to store internal variables and state. It should be at least 150 bytes plus 4 bytes per function call in the cog.

Lines 14–19: Constants used by all cogs.

Line 24: Declare and reserve space for the stack here.

Lines 27–31: Shared variables have a `volatile` qualifier to signal the compiler not to remove them during optimization. If the compiler thinks a variable is unused, it won't reserve space for it. However, it is possible that a variable is used by a Spin or PASM cog unknown to the compiler.

Part 2, shown in Listing 12-5, is the code for the cog. Define a function that is called by the main cog. This function (and any functions that it calls) will run in a separate cog from the main cog. However, this cog will have access to the variables declared earlier. Those are global variables and available to all functions in the file.

Listing 12-5. Part 2: Compression Cog Code in File compr_cog0.c

```
/* cog code - comprCog
   use nsamps and ncompr to signal with main cog
     start compression when nsamps != 0
     signal completion with ncompr > 0
```

```
 5       signal error with ncompr = 0
 6     compress sampsBuf to packBuf - NOT DONE YET
 7     populate comprCodesBuf - NOT DONE YET
 8     - args: pointer to memory space PAR - UNUSED
 9     - return: none
10   */
11  void comprCog(void *p) {
12    int i, nc, nbytes, codenum, codeshift, code;
13    int diff, adiff;
14
15    while (1) {
16      if (nsamps == 0) {
17        continue; // loop continuously while nsamps is 0
18      } else {
19        // perform the compression here
20        if (nsamps > NSAMPS_MAX || nsamps < -NSAMPS_MAX) {
21          ncompr = 0; // signal error
22          nsamps = 0;
23          continue;
24        }
25        ncompr = 3; // signal completion
26        nsamps = 0; // prevent another cycle from starting
27      }
28    }
29  }
```

Line 11: The cog function definition. `void comprCog()` means that this doesn't return any value. The argument (`void *p`) means that an address is passed in—this is the equivalent of `PAR`. However, because we are using the global variables to pass information between cogs, we won't use `PAR`.

Lines 12–13: Local variables used by the cog.

Line 15: Infinite loop that contains the actual code that does the work of the cog.

Lines 16–18: If nsamps is set to nonzero by main, enter the section that does the work.

Lines 20–26: Error checking and, finally, the work of this cog. Set ncompr to 3 and nsamps to 0. (We will add code to do the actual compression later.)

Part 3, shown in Listing 12-6, is the entry point for the program, including the main function and the code that runs first. Again, this cog has access to the global variables. It also starts the new cog and interacts with it by setting and reading variables in those global variables.

Listing 12-6. Part 3: Main Code in File compr_cog0.c

```
/* main cog - initializes variables and starts new cogs.
 * don 't exit - start infinite loop as the last thing.
 */
int main(void)
{
  int comprCogId = -1;
  int i;

  nsamps = 0;
  ncompr = -1;

  printf(" starting main \n");

  /* start a new cog with
   * (1) address of function to run in the new cog
   * (2) address of the memory to pass to the function
   * (3) address of the stack
   * (4) size of the stack, in bytes
   */
20    comprCogId = cogstart (&comprCog, NULL, comprCogStack, ↩
      STACK_SIZE_BYTES);
21    if(comprCogId < 0) {
22      printf(" error starting compr cog \n");
23      while (1) {;}
24    }
25
26    printf(" started compression cog %d\n", comprCogId);
27
28    /* start the compression cog by setting nsamps to 1 */
29    sampsBuf[0] = 0xEFCDAB;
30    nsamps = 1;
31
32    /* wait until the compression cog sets ncompr to a non -neg, ↩
      number */
33    while(ncompr < 0) {
34      ;
35    }
36
37    printf(" nsamps = %d, ncompr = %d\n", nsamps, ncompr);
38    printf(" samp0 = %x, packBuf = %x %x %x\n", sampsBuf[0], ↩
      packBuf[0], packBuf[1], packBuf[2]);
39
40    while (1)
41    {
42      ;
43    }
44  }
```

Line 20: This is the key in `main`. The `cogstart` function takes four arguments. The first is the address of the function to place in the new cog: `&comprCog`. The ampersand symbol (&) in C is to obtain the address of a variable or function. The next argument is the address of memory that will be passed to the cog in PAR (the "locker number" in the analogy in Chapter 6). In this case, because we are using global variables to exchange information, we won't use PAR and can pass NULL (which is, as it states, the null pointer). The third and fourth arguments are the address of the reserved stack space and its length in bytes, respectively. The stack is a region of memory that the kernel needs to store variables and counters.

Line 30: Here we set nsamps=1, which signals the compression cog to begin its work.

Lines 33–35: The compression cog will set ncompr to a non-negative number when it completes its work. The main cog waits in this loop until it sees that the compression cog is finished.

Lines 37–38: Print out the results. nsamps should now be zero, and ncompr should now be non-negative.

Line 40: Enter an infinite loop, doing nothing.

The output from running this program is as follows:

```
starting main
started compression cog 1
nsamps = 0, ncompr = 3
samp0 = EFCDAB, packBuf = 0 0 0
```

We have shown that we can communicate with the compression cog. How fast is it? To compare this to the Spin and PASM compression codes from the previous chapters, let's implement the compression code.

12.2.4 Compression Code in C

We will edit comprCog to include the packing. Replace the code with the code in Listing 12-7. This forms the difference between successive samples and checks the length of the difference. Depending on that length, it saves the difference as either 1, 2, or 3 bytes of packBuf. (For simplicity I haven't included the part that populates the compression code comprCodesBuf.)

Listing 12-7. Compression Code Version 2 (ch11/compr cog1.side)

```
/* cog code - comprCog
 use nsamps and ncompr to signal with main cog
   start compression when nsamps != 0
   signal completion with ncmopr > 0
   signal error with ncompr = 0
   compress sampsBuf to packBuf
   populate comprCodesBuf - NOT YET DONE
   - args: pointer to memory space PAR - UNUSED
   - return: none
 */
void comprCog(void *p) {
  int i, nc, nbytes, codenum, codeshift, code;
  int diff, adiff;

  while (1) {
    if(nsamps == 0) {
      continue; // loop continuously while nsamps is 0
    } else {
      // perform the compression here
      if(nsamps > NSAMPS_MAX || nsamps < -NSAMPS_MAX) {
        ncompr = 0; // signal error
        nsamps = 0;
        continue;
      }
      for(i=0; i< nsamps; i++) {
        if(i ==0) { // first samp
          memcpy(packBuf,(char *)sampsBuf, 3);
          nc = 3;
        } else {
          diff = sampsBuf[i] - sampsBuf[i -1];
31            adiff = abs(diff);
32            if(adiff < TWO_BYTES) {
33              nbytes = 1;
34            } else if(adiff < THREE_BYTES) {
35              nbytes = 2;
36            } else {
37              nbytes = 3;
38            }
39            // copy the correct number of bytes from diff
40            // to packBuf
41            memcpy(packBuf +nc,(char *)diff, nbytes);
42            nc += nbytes;
43          }
44        }
45        ncompr = nc; // signal completion
46        nsamps = 0;  // prevent another cycle from starting
47      }
48    }
49  }
```

Line 26–28: Here the first sample is packed. The `memcpy` function will copy three bytes from the memory location `sampsBuf` to the memory location `packBuf`. There are no indices on the two arrays because we are operating on the start of both arrays (`sampsBuf[0]` is copied to `packBuf[0..2]`).

Lines 30–38: Form the difference and check the length of its absolute value.

Line 41: Copy the appropriate number of bytes of the difference to `packBuf`.

Lines 45–46: Signal the main cog that the compression is complete by setting `ncompr` to the number of bytes used in `packBuf`. Set `nsamps` to zero so that the loop doesn't start again.

Add the following to the main cog:

```
printf(" nsamps = %d, ncompr = %d\n", nsamps, ncompr);
printf(" nsamps = %d, ncompr = %d\n", nsamps, ncompr);
printf(" samp0 = %x, packBuf = %x %x %x\n", sampsBuf[0], ➥
packBuf[0],
% packBuf[1], packBuf[2]);

// NEW CODE STARTS HERE >>>
for(i=0; i< NSAMPS_MAX; i++) {
  sampsBuf[i] = 10000*(i +1000);
}

ncompr = -1;
t0 = CNT;
nsamps =128;
/* wait until the compression cog sets ncompr to a non -neg ➥
number */
while(ncompr < 0) {
  ;
}
t0 = CNT - t0;
printf(" nsamps = %d, ncompr = %d\n", nsamps, ncompr);
printf(" samp0 = %x, packBuf = %x %x %x\n", sampsBuf[0], ➥
packBuf[0], packBuf[1], packBuf[2]);
printf(" dt = %d\n", t0);
// NEW CODE ENDS HERE <<<


while (1)
{
  ;
}
```

Lines 7–9: Initialize `sampsBuf`.

Lines 12–18: Time how long it takes to perform the compression of 128 samples.

The results are as follows:

```
starting main
started compression cog 1
nsamps = 0, ncompr = 3
samp0 = EFCDAB, packBuf = AB CD EF
nsamps = 0, ncompr = 384
samp0 = 989680, packBuf = 80 96 98
dt = 151600
```

Table 12-1 compares the time taken to perform the compression in different languages. Clearly the fastest language is PASM, with C being about one-fifth the speed of PASM.

Table 12-1. *Comparison of Time Taken to Compress Data Using Different Methods*

Language	Number of Counts to Compress 128 Samples
Spin code	1.5 million counts
PASM code	22,000 counts
C code (LMM)	150,000 counts

Spin is 1/10th the speed of C. In the next chapter, we will program the compression cog using Cog-C mode, where the cog code is downloaded to the cog all at once and run there. (Recall that in LMM mode the code is held on the hub, and one instruction at a time is downloaded and run on the cog.)

Because I know that I won't be using pure-C mode for the final version, I'm not going to complete the compression and decompression code—that can be an exercise for you!

12.3 Summary

The simplest multicog technique in C is the large memory model (Listing 12-8 has a template to get you started). Here, all the code for *all* the cogs is stored in the hub, along with a *kernel*, which is a small program that copies instructions to each cog as needed and executes them. The code for each cog is defined as a function that is called by the `cogstart` instruction.

- Set aside a chunk of memory for the stack.
- Define variables that will be shared by all the cogs.
- Define a function `pureCCog` whose code will be run in a separate cog (note that the external variables are available here).
- In the main function, call `cogstart` with the address of `pureCCog`. The external variables are available here too.

Listing 12-8. Template for Pure-C Code

```
# define STACK_SIZE_INT 100
# define STACK_SIZE_BYTES 4 * STACK_SIZE_INT

// This is a critical number that is difficult to estimate
// In a later chapter I will discuss how to set it
static unsigned int pureCCogStack[STACK_SIZE_INT];

// these are shared with all cogs and must be
// declared `` volatile '''
volatile int variable1;
volatile int variable2;
volatile int dataArray[100];

// function to run in new cog - mustn't return
void pureCCog(void *p) {
  while (1) {
    ...
    // access variable1, variable2, and dataArray[]
  }
}

// the main function - mustn't return
int main() {
  int pureCCogId;
  // the calling protocol for new cogs
  pureCCogId = cogstart (&pureCCog, NULL, pureCCogStack, ↵
  STACK_SIZE_BYTES);
  while (1) {
    ...
    // main cog can access variable1, variable2, dataArray[]
  }
}
```

CHAPTER 13

Programming in Cog-C Mode

In the previous chapter, we programmed the Propeller in the large memory model where the code was all stored in hub memory and instructions were downloaded to a cog one at a time for execution. This exacts a performance penalty. If the code you want to run on a cog will fit entirely within the cog (496 longs), then you can write that code in such a way that it is copied to the cog all at once and runs on the cog natively.

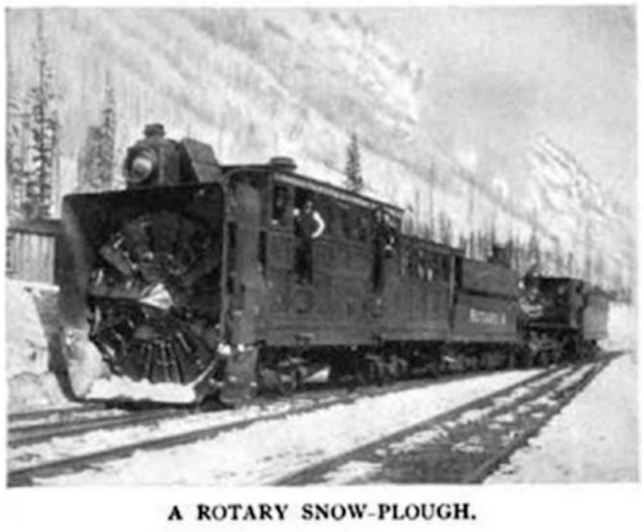


Figure 13-1. *A rotary snow plough used for clearing track. From "The World's Work, Volume 1," WH Page, AW Page, Doubleday, 1901. Available for free download from Google Books* `https://books.google.com/books?id=688YPNQ5HNwC`.

13.1 Cog-C Mixed Mode Programming

Here we will write the main cog in the same way as in the previous chapter but will place the compression code in a separate file whose extension is `cogc`. This special extension will signal the compiler that the code in that file will be copied to a cog all at once.

In SimpleIDE start a new project named `compr_cogc` and create three files.

- `compr_cogc.c` is where the code for the main cog resides.
- `compr.cogc` is where the code for the compression cog resides.
- `compr_cogc.h` is a header file that contains common variable and constant declarations.

13.1.1 Main Cog Code

Listing 13-1 shows that the main cog code is similar to the code in the previous chapter with a few significant changes.

Listing 13-1. Contents of compr_cogc.c Showing Modifications from Previous Chapter

```
#include <stdio.h>
#include <propeller.h>
// ADD THIS >>>
#include " compr_cogc.h"
// <<<

/* defines */

/* global variables */

// ADD THIS >>>
// reserved space to be passed to startComprCog
struct cogmem_t {
  unsigned int stack[STACK_SIZE_BYTES >> 2];
  volatile struct locker_t locker ;
} cogmem ;
// <<<

// shared vars
volatile int nsamps ;
volatile int ncompr ;
volatile int sampsBuf[NSAMPS_MAX];
volatile char packBuf[NSAMPS_MAX <<2]; // 128 * 4
volatile int comprCodesBuf[NSAMPS_MAX >>4]; // 128 / 16

```

```
26 // ADD THIS >>>
27 int startComprCog(volatile void *p) {
28   extern unsigned int _load_start_compr_cog [];
29   return cognew(_load_start_compr_cog, p);
30 }
31 // >>>
32
33 // DELETE THE comprCog FUNCTION
34 ...
35
36 // in main ...
37
38 ...
39
40   printf (" starting main \n");
41
42 // CHANGE TO THIS >>>
43   comprCogId = startComprCog (&cogmem.locker);
44 // <<<
45
46   if(comprCogId < 0) {
47     printf (" error starting compr cog \n");
48     while (1) {;}
49   }
50
51 ...
```

- **Lines 13–16**: Declare a structure `struct cogmem_t {...} cogmem` with two members: an array named `stack` and another structure named `struct locker_t locker`. The `cogmem` structure will keep the memory for the stack and for the locker in adjacent space. The address of the locker struct will be passed to the new cog in the PAR register. Note that in this example we won't be using the locker but still define it because the kernel expects this arrangement (stack followed by the locker variables). The definition of struct locker_t is in the header file compr_cogc.h.

```
/* define the struct for passing data via PAR to the cog -- UNUSED */
struct locker_t {
};
```

- **Lines 27–30**: A function that starts the compression cog. This makes reference to the "magical" address location of _load_start_compr_cog. This form of this variable is always as follows:

  _load_start_<COGCFILENAME>_cog, where COGCFILENAME is the name of the file that contains the cog code (in our case, that file name is compr.cogc, so we put compr) in the name.

  The cognew function takes two arguments: that magical variable and the pointer p passed to the function. p points to the struct locker_t locker memory and will be placed in PAR. In this example, it is *unused*, but we still invoke it in all its messy glory so that if you ever want to use it, you know how!

- **Line 43**: We start the cog by calling the startComprCog function. It takes one variable, which is the address of the struct locker_t variable in the cogmem structure: &cogmem.locker.

When the main cog runs, it will call `comprCogStart` with the address of the start of the locker memory block (`&cogmem.locker`). Remember, the `&` operator returns the address of the variable, and `cogmem.locker` refers to the variable `locker` in the struct `cogmem`. Yes, I know it is messy, but if you copy this pattern slavishly, it should work.

13.1.2 Compression Cog-C Code

The compression code is placed in its own file, `compr.cogc`, as shown in Listing 13-2. (You must have the `cogc` extension.) Whatever name you choose for this file is what shows up in the `cognew` command `_load_start_compr_cog`.

Listing 13-2. Contents of compr.cogc

```
#include "compr_cogc.h"
#include <propeller.h>

// shared vars
extern volatile int nsamps ;
extern volatile int ncompr ;
extern volatile int sampsBuf[NSAMPS_MAX];
extern volatile char packBuf[NSAMPS_MAX <<2]; // 128 * 4
extern volatile int comprCodesBuf[NSAMPS_MAX >>4]; // 128 / 16

/* cog code - compr
   use nsamps and ncompr to signal with main cog
     start compression when nsamps != 0
     signal completion with ncmopr > 0
     signal error with ncompr = 0
   compress sampsBuf to packBuf
   populate comprCodesBuf
   - args : pointer to memory space PAR - UNUSED
   - return : none
 */

void main (struct locker_t *p) {
  int i, nc, nbytes, codenum, codeshift, code ;
  int diff, adiff ;

  while (1) {
    if (nsamps == 0) {
      continue ; // loop continuously while nsamps is 0
    } else {

      // perform the compression here
      if (nsamps > NSAMPS_MAX || nsamps < -NSAMPS_MAX) {
        ncompr = 0; // signal error
        nsamps = 0;
        continue ;
      }
      for(i=0; i< nsamps ; i++) {
        if(i ==0) { // first samp
          memcpy (packBuf, (char *) sampsBuf, 3);
          nc = 3;
        } else {
          diff = sampsBuf[i] - sampsBuf[i -1];
          adiff = abs(diff);
          if (adiff < TWO_BYTES) {
            nbytes = 1;
            code = CODE08 ;
          } else if (adiff < THREE_BYTES) {
            nbytes = 2;
            code = CODE16 ;
50       } else {
51         nbytes = 3;
52         code = CODE24 ;
53       }
54       // copy the correct number of bytes from diff
55       // to packBuf
56       memcpy (packBuf +nc, (char *) diff, nbytes);
57       nc += nbytes ;
58     }
59    }
60    ncompr = nc; // signal completion
61    nsamps = 0; // prevent another cycle from starting
62   }
63  }
64 }
```

- **Lines 5–9**: These are variables that are shared between the main cog and this cog. The `extern` qualifier tells the compiler not to reserve new space but that this variable has been defined in another file. From now on, any reference to, for example, `nsamps` will reference the same variable as in the main cog (where it was originally defined). The `volatile` qualifier tells the compiler that even if it looks like this variable isn't used, don't optimize it away. It could be modified in, for example, the main cog.
- **Line 22**: The cog code is placed in its own `main` function that should never return. It takes one argument, a pointer to a memory block (this is the equivalent of `PAR`). In this example, this is *unused* because we prefer to use the shared variables.

Everything else is the same as in the previous chapter.

13.1.3 Header File compr_cogc.h

Listing 13-3 shows the contents of `compr_cogc.h`.

Listing 13-3. Contents of compr_cogc.h

```
// size of stack in bytes
#define STACK_SIZE_BYTES 200
// compression constants
#define NSAMPS_MAX 128
#define CODE08 0b01
#define CODE16 0b10
#define CODE24 0b11
#define TWO_BYTES 0x7F // any diff values greater than this are 2 bytes
#define THREE_BYTES 0 x7FF // diff valus greater than this are 3 bytes

/* define the struct for passing data via PAR to the cog -- UNUSED */
struct locker_t {
};
```

This is the front matter that is used by both the main cog and the compression cog (both have the line `#include "compr_cogc.h"`). The `struct locker_t` declaration is empty because it is a placeholder that we don't use.

13.1.4 Running the Cog-C Code

Make sure that you have chosen LMM Main Ram as your memory model on the Project Options tab. (Even though you have chosen LMM, because the `compr.cogc` file has a `.cogc` extension, it will be compiled in Cog-C mode and copied to a new cog and run in that cog natively.)

```
starting main
started compression cog 1
done... nsamps = 0, ncompr = 3
samp0 = EFCDAB, packBuf = AB CD EF
nsamps = 0, ncompr = 384
samp0 = 989680, packBuf = 80 96 98
dt = 42064
```

Let's compare the running speed to the other ways of compressing 128 longs. See Table 13-1.

Table 13-1. *Comparison of Compression Speeds with Cog-C Mode Added*

Language	Number of Counts to Compress 128 Samples (Smaller Is Better)
Spin code	1.5 million counts
PASM code	22,000 counts
C code (LMM only)	150,000 counts
Cog-C mode	42,000 counts

Clearly, programming in Cog-C mode improves speed by about a factor of three to four over LMM C mode. As you can see, PASM is still the fastest method, but Cog-C is no slouch!

13.2 Summary

We can start a new cog that is running in *Cog-C* mode, in which the C code is compiled to PASM and copied in its entirety to a cog and run there. Of course, the compiled code must be less than 496 longs (the size of cog memory).

- In the main file, we must set aside a chunk of memory for the stack and the "locker" (`struct cogmem_t`); a template for the main file is in Listing 13-4.
- Define shared variables that will be available to all cogs (`volatile int x`).
- Define a function that starts the cog (`int startMyCogC(...)`).
- Create a file named `myCogC.cogc` that contains the code to be loaded to the new cog; a template for the cog-C file is in Listing 13-5.
- In the main file, call the `startMyCogC` function.
- In the `.cogc` file, refer to the shared variables using `extern volatile int x` so the cog can use them.

Listing 13-4. Contents of main.c for Cog-C Mixed Mode

```
// in main .c
#define STACK_SIZE_INTS 50

// put this in a mycogc .h file (common to this file and ↩
   mycogc .cogc)
// #include " mycogc .h"
struct cogmem_t {
  unsigned int stack[STACK_SIZE_INTS];
  volatile struct locker_t locker ;
};

// declare the cog memory for the new cog
// there must be a different memory space for each cog
struct cogmem_t myCogCMem ;

// shared with all cogs
volatile int variable1 ;
volatile int variable2 ;
volatile int dataArray[100];

// start the new cog ...
int startMyCogC(volatile void * parptr) {
  extern unsigned int _load_start_myCogC_cog[];
  return cognew(_load_start_myCogC_cog, parptr);
}

int main () {
  int myCogCId ;
  // start the new cog . the address of locker is passed to
  // the cognew command as parptr
  myCogCId = startMyCogC(&myCogCMem . locker);
...
  while (1) {
    ...
    // access variable1, variable2, dataArray [] in main cog
  }
}
```

Listing 13-5. Contents of the .cogc File

```
// contents of myCogC .cogc

// put this in a mycogc .h file and
// # include " mycogc .h"
struct cogmem_t {
  unsigned int stack [STACK_SIZE_INTS];
  volatile struct locker_t locker ;
};

// any variables declared in another file
// must be set as `` extern '' so that the
// compiler knows where to find them.
extern volatile int variable1 ;
extern volatile int variable2 ;
extern volatile int dataArray [100];

// the code that will run in the new cog
// must be small enough to fit in 496 longs.
// the compiler will complain if it is too big
void main(struct locker_t *p)
  while (1) {
    ...
    // access variable1, variable2, and dataArray [] in 2nd cog
  }
}
```

CHAPTER 14

Programming with C and PASM

In this chapter, we will look at the combination of using C for the main cog (and any other cogs that are not required to be fast) and PASM for the critical cog that must run as fast as possible. For this mode, we must use the PAR method of passing variables between the main cog and the compression cog (in pure-C programming, we use shared variables, but that isn't possible here). Hitching together fast and slow components has been done before - see Figure 14-1 for an example!

S. Anandakrishnan, *Propeller Programming*, https://doi.org/10.1007/978-1-4842-3354-2_14

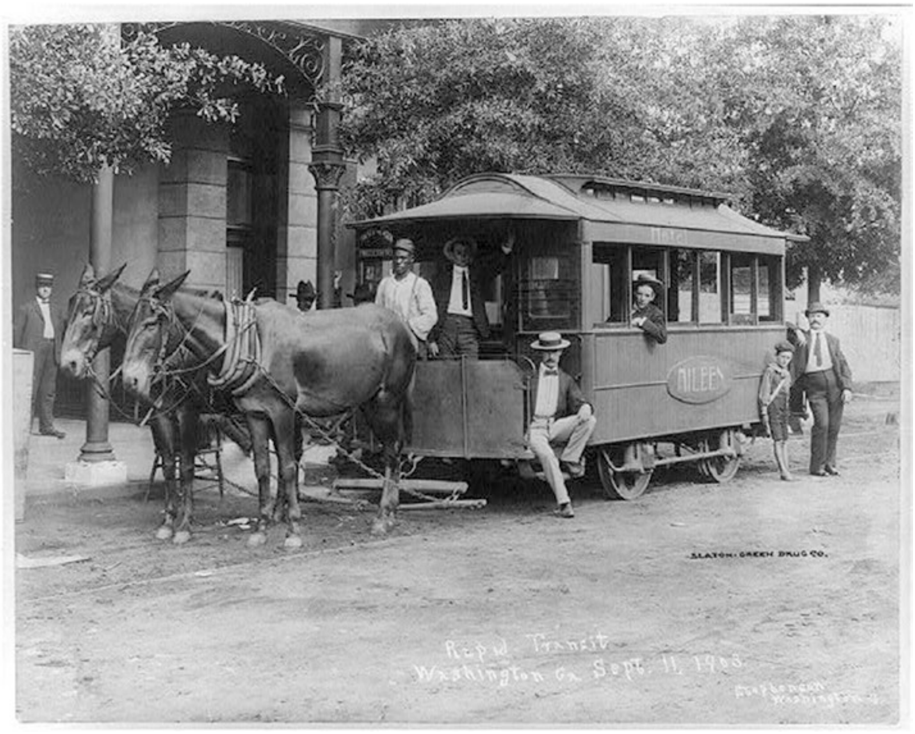


Figure 14-1. *Rapid Transit, Washington, GA 1903. Photographer JW Stephenson. Library of Congress archives (`http://www.loc.gov/pictures/item/2012646774`).*

In summary, we will do the following:

- In the C program, we will create a block of memory (using a `struct`) that contains the variables we want to pass to the PASM cog. Because we use a `struct`, the variables are in contiguous memory.
- We create a Spin/PASM file that has one Spin method (`START`) that calls `cognew` to start a PASM cog. The address of the `struct` is passed to this cog in `PAR`.
- Now the C program and the PASM cog can interact through the variables in the `struct`.

14.1 Compression with C and PASM

Create a new project in SimpleIDE called `compr_c_pasm` and create two files: `compr_c_pasm.c` and `compr.spin`.

14.1.1 C Code for Main Cog

Listing 14-1 shows the contents of the PASM file.

Listing 14-1. Contents of ch12/compr_c_pasm.c

```
/* libraries */
#include <stdio.h>
#include <propeller.h>

/* defines */

// compression constants
#define NSAMPS_MAX 128

/* global variables */
// reserved space to be passed to startComprPASMCog
volatile struct locker_t {
  int nsamps ;
  int ncompr ;
  int *psampsBuf ;
  unsigned char *ppackBuf ;
  int *pcomprCodesBuf ;
} locker ;

volatile int sampsBuf[NSAMPS_MAX];
volatile unsigned char packBuf[NSAMPS_MAX <<2]; // 128 * 4
volatile int comprCodesBuf[NSAMPS_MAX >>4]; // 128 / 16

int startComprPASMCog(unsigned int * parptr) {
  extern unsigned int binary_compr_dat_start[];
  return cognew(binary_compr_dat_start, parptr);
}


/* main cog - initializes variables and starts new cogs.
 * don 't exit - start infinite loop as the last thing.
 */
int main(void)
{
  int comprCogId = -1;
  int i;
  unsigned int t0;

  locker.nsamps = 0;
  locker.ncompr = -1;
  locker.psampsBuf = sampsBuf ;
  locker.ppackBuf = packBuf ;
  locker.pcomprCodesBuf = comprCodesBuf ;

  printf (" starting main \n");

  comprCogId = startComprPASMCog (&locker);
  if(comprCogId < 0) {
    printf (" error starting compr cog \n");
    while (1) {;}
  }

53    printf(" started compression cog %d\n", comprCogId);
54
55    /* start the compression cog by setting nsamps to 1 */
56    sampsBuf [0] = 0 xEFCDAB ;
57    locker.nsamps = 1; //= cogmem.locker.nsamps = 1;
58
59    /* wait until the compression cog sets ncompr to a ↵
      non -neg number */
60    while(locker.ncompr < 0) {
61      ;
62    }
63
64    printf(" done ... nsamps = %d, ncompr = %d\n", ↵
      locker.nsamps, locker.ncompr);
65    printf(" samp0 = %x, packBuf = %x %x %x\n", sampsBuf ↵
      [0], packBuf [0], packBuf [1], packBuf [2]) ;
66
67    while (1)
68    {
69      ;// do nothing
70    }
71  }
```

- **Lines 12–18**: Declare a structure that contains all the variables to be passed to the PASM cog. By placing them in a `struct`, you ensure that they will remain contiguous and in order. The PASM cog finds variables by knowing their address relative to the start of the memory location passed to it in `PAR`. So, the PASM cog expects `nsamps` to be at the start of that memory block and `ncompr` to be 4 bytes past that.

- **Lines 15–17**: Here we place the addresses for the three arrays. `psampsBuf` is the address of `sampsBuf` and so on. Pointers in C are 4 bytes long, so the three pointers are at the correct locations that the PASM cog expects. The expression `int *p` says that `p` is a pointer to an `int` array.
- **Lines 20–21**: The arrays themselves are declared here. They are also qualified to be `volatile` so the compiler won't inadvertently remove them.
- **Lines 24–27**: This is the function that starts the PASM cog. It has a "magic" invocation as well. `binary_compr_dat_start` is the address in memory of the code to be written to the cog. The variable has the form `binary_<PASMFILENAME>_dat_start`, where `PASMFILENAME` has a `.spin` extension (in our case, `compr.spin`).
- **Lines 39–43**: The lockers are populated. A member of a `struct` is accessed via `locker.nsamps`, and so on. The address of an array, such as `sampsBuf[]`, can be obtained by simply mentioning the name of the array, as in `locker.psampsBuf = sampsBuf` and so on.
- **Line 47**: Here we call the function that starts the cog and pass the address of the beginning of the locker: `&locker`. The address of the first member of a `struct` is the same as the address of the `struct` variable; thus, the address of `nsamps` is given by `&locker` (remember, the `&` operator returns the address of the variable).

14.1.2 PASM Code

The PASM code that will run in the new cog is placed in a file with the `.spin` extension (see Listing 14-2). The file name will appear in the extern variable `binary_compr_dat_start` in the main code.

Listing 14-2. Contents of compr.spin

```
 1
 2  PUB START (locker)
 3    cognew (@STEIM, locker)
 4
 5
 6  DAT 'steim
 7  ''
 8  ''
 9
10  STEIM org 0
11    ' copy the param addresses
12    mov _cnsPtr, par
13    mov _cncomprPtr, par
14    add _cncomprPtr, #4
15  ...
```

- **Lines 2–3**: Define a public method named `START` that calls the Spin method `cognew`. As in regular Spin code, this has two arguments: the address of the `PASM` code we want to run (in this case `@STEIM`) and the memory location to place in `PAR` (in this case `locker`). When the main C cog starts the cog with the following, the memory location `parptr` is passed to this `START` method and then passed on to the Spin `cognew` method here.

  ```
  cognew(binary_compr_dat_start, parptr)
  ```

- **Lines 6–15**: This code is lifted directly from the PASM code in Chapter 9.

Running this code results in compression speeds almost identical to the PASM case (as it should, this is really the same code running in the same way). See Table 14-1.

Table 14-1. *Comparison of Compression Speeds with Cog-C Mode Added*

Language	Number of Counts to Compress 128 Samples (Smaller Is Better)
Spin code	1.5 million counts
PASM code	22,000 counts
C code (LMM only)	150,000 counts
Cog-C mode	42,000 counts
C and PASM code	22,000 counts

14.2 Summary

You can start a pure-PASM cog if, for example, you have some tested and fast code that you want to reuse. To do so, you must have two files: one in C and one in Spin and PASM. The C program will create a block of memory (in the hub). That memory location is passed to the Spin method, which passes it to the PASM cog.

The main C file in Listing 14-3 has a template for creating the memory (`struct locker_t ... locker;`) and calling the Spin method `START` in the file `fastCog.spin` (Listing 14-4): `cognew(binary_fastCog_dat_start, parptr);`.

Listing 14-3. Template for C/PASM: C File

```
// Contents of main.c

// the address of the locker struct is equal to the address of the
// first field in the struct. That address is passed to the
// PASM cog in PAR. The PASM cog will determine the addresses
// of the other variables; they are in consecutive ⮐
   memory locations
struct locker_t {
  int variable1 ;
  int variable2 ;
  int * array ; // this is a pointer to an array
} locker ;

// start the cog
int startFastCog(unsigned int * parptr) {
  extern unsigned int binary_fastCog_dat_start [];
  return cognew(binary_fastCog_dat_start, parptr);
}

// this array is only available to the main cog
// in order to pass it to the PASM cog, copy it 's
// address to the locker
volatile int dataArray [100];

int main () {
  int fastCogId ;
  locker.variable1 =42; // populate the locker
  locker.variable2 =12;
  locker.array = dataArray ; // copy the address of the array to the locker
  // start the PASM cog
  fastCogId = startFastCog (& locker);

  // from here on, locker.variable1, etc may be modified by fastCog
  while (1) {
    ;
  }
}
// main.c ends here
```

The Spin/PASM file (Listing 14-4) has a single Spin method (START) whose argument is the address of memory (in the hub) that we want to share with the PASM cog. This address is used as the second argument to the cognew call that launches the PASM cog (and, therefore, that address is placed in PAR). In the PASM cog, we can modify memory in the hub that the C program is, presumably, interested in.

Listing 14-4. Template for C/PASM: PASM File

```
' the contents of fastCog.spin
' locker is the address of the " locker " variable from the main cog
PUB START(locker)
  cognew(@FASTCOG, locker)

DAT 'fastcog
FASTCOG org 0
  mov _var1Ptr, par ' par contains the address of locker, which
                    ' is also the address of the first field, variable1
  mov _var2Ptr, par
  mov _arrayPtr, par
  add _var2Ptr, #4 ' variable2 is 4 bytes after variable1
  add _arrayPtr, #8 ' the * address * of the array is 8 ↵
  bytes after variable1
...
' and we 're off to the races
  rdlong _cVar1, _var1Ptr ' get C's locker.variable1
  add _cVar1, #42         ' do something
  wrlong _cVar1, _var1Ptr ' write it back

  ...
_var1Ptr res 1
_var2Ptr res 1
_arrayPtr res 1
_cVar1 res 1
FIT 496
'fastCog.spin ends here
```

CHAPTER 15

Hardware I/O with C

We can work with the hardware in C (setting and reading pins and counters) in one of three ways: using direct calls to the registers (`INA`, `DIRA`, etc.), using the `simpletools` utility library, and using C code and *injecting* PASM code in critical sections. This is known as *inline assembler* mode.

Let's begin with the simpler library method and then move on to the others.

We will write an SPI master and slave and put each in its own cog (see Section 7.1 for details on SPI). The SPI slave stands in for a data acquisition device that produces data. The SPI master is the interface to that "device." The main cog works only with the SPI master to receive data and process, print, or store it.

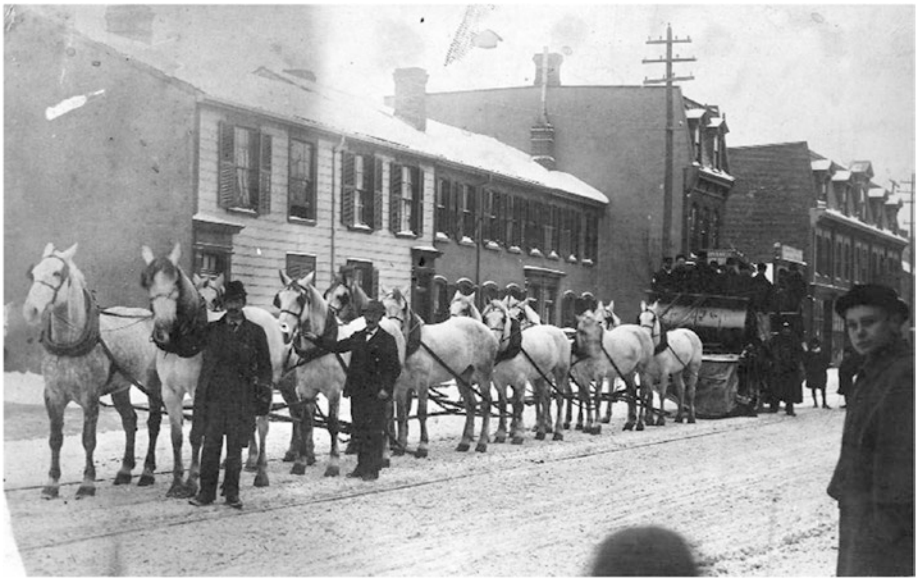


***Figure 15-1.** Twelve-horse team pulling snow sweeper. Toronto, 1891. From City of Toronto archives. Image in public domain.* *https://commons.wikimedia.org/wiki/File%3ATwelve_horse_team_pulling_snow_sweeper.jpg*.

15.1 Referencing Hardware in C

By including the `propeller.h` library, the following functions and variables are available (unlike Spin and PASM, these are case-sensitive):

- `DIRA` sets the direction of the 32 I/O pins. If a bit *N* is a 1, then that pin will be an output. All cogs have their own copy of the `DIRA` register. More than one cog can set a pin as output, and if any of those cogs drives the pin high (by setting that bit in the `OUTA` register), then that pin will go high.

- OUTA sets the value of pin *N* to either high or low by setting the bit in that position to 1 or 0, respectively. The pin itself will be driven high or low only if the associated bit in the DIRA register is a 1.
- INA (read-only) reflects the state of the pins. If the pin is high, the bit in that position will be a 1.
- CNT (read-only) is the value of the internal counter, which increments once each clock cycle.
- waitpne and waitpeq wait for the state of the inputs to match a requested state (see Chapter 7).
- waitcnt is like Spin's waitcnt; it takes one argument, target, and the cog is paused until the counter equals the target value. waitcnt2 is like the PASM waitcnt, with two arguments: a target value and a delta value. The cog is paused until the target count is reached. The target is incremented by delta for repeated and reliable delays.
- locknew, lockret, lockset, and lockclr are all as in Spin and PASM.
- C has some bitwise operators such as AND (&), OR (|), and XOR (^), and shift left (<<) and shift right (>>). It is missing the rotate left and right operators of Spin and PASM, the reverse bits operator, and the arithmetic shift operator. There are functions for performing those operations in C (see http://graphics.stanford.edu/~seander/bithacks.html).

15.2 simpletools Library

By including the simpletools library (with #include <simpletools.h>), you have access to a number of functions that simplify hardware manipulations. However, the authors of simpletools warn that it is best to use these functions in straight C code (LMM-only mode). This is because the library is too large to fit in a cog (remember, cog memory is limited to 496 longs). The library consists of a number of functions and variables.[1]

For example, set a pin with high(N), low(N), or toggle(N). Get the value of an input pin with v = input(pin). There are more-complex ways to set the direction and get the state of a single pin or of multiple pins. There are functions to use the I2C and SPI protocols as well as a full duplex serial port.

Flashing an LED on the QuickStart board (from http://learn.parallax.com/tutorials) is self-explanatory, as shown in Listing 15-1.

Listing 15-1. Hello Blinky: Using simpletools.h to Toggle an LED

```
#include " simpletools.h"
#define LED0 16 # pin number for LED0 on Quickstart board.
int main ()
{
  while (1) {
    high (LED0);
    pause (100) ; // Wait 100 ms (1/10 sec)
    low (LED0);
    pause (100) ;
  }
}
```

[1]See SimpleIDE/Learn/Simple%20Libraries/Utility/libsimpletools/Documentation%20simpletools%20Library.html; the SimpleIDE folder is in the Documents folder.

15.3 Using the Registers Directly

Particularly in Cog-C mode or whenever speed or flexibility is an issue, you will want to address the input and output registers directly.

15.3.1 Set a Pin

Set a bit, as shown in Listing 15-2.

Listing 15-2. Setting a Pin in C Using the OUTA Register

```
 1  #include <propeller.h>
 2  #define LED0 16  // pin number for LED0 on Quickstart board.
 3  #define LED0MASK (1U << LED0)
 4  int main () {
 5    unsigned int delayTime = CLKFREQ /2;
 6    OUTA = 0;  // set all bits to zero
 7    DIRA |= LED0MASK ; // set pin 16 to output
 8    while (1) {
 9      OUTA ^= LED0MASK ;  // toggle pin 16
10      waitcnt (CNT + delayTime);
11    }
12  }
```

- **Line 3**: Create a *mask* where bit 16 is high and the others are low.
- **Lines 6–7**: Set the output register to all 0s and then set the output direction for pin 16 to 1. The expression `DIRA |= LED0MASK` will perform a bitwise OR of the `DIRA` register and the `LED0MASK` and assign the result back to `DIRA`. The result is that bit 16 in `DIRA` is set to 1 (output).

- **Line 9**: Perform an exclusive OR of `OUTA` and `LED0MASK`. In an exclusive OR, compare the two arguments bit by bit, and return a 1 if and only if one of the two bits is 1. If both are 0 or both are 1, then the bit is set to 0. Thus, as bit 16 of `LED0MASK` is always 1, if bit 16 of `OUTA` is 0, then the exclusive OR will set bit 16 of `OUTA` to 1 (1^0 = 1). If bit 16 of `OUTA` is 1, then the exclusive OR will set it to 0 (1^1 = 0).

15.3.2 Read a Pin

The QuickStart board doesn't have a button, but it has a touchpad. Here you set the touchpad pin high and read its value after a short time. If you are touching the pad, then the conduction of your skin will quickly force the pin low. If you aren't touching it, then the pin will remain high for a long time (it will eventually decay to low because there is a large resistor to ground that will eventually pull it low).

In Listing 15-3 we toggle the LED every time we touch pad 0.

Listing 15-3. Toggle an LED Using Registers in C

```
 1  #include <propeller.h>
 2  #define LED0 16  // pin number for LED0 on Quickstart board.
 3  #define LED0Mask (1U << LED0)
 4  #define PAD0 0  // pin number for PAD0 on Quickstart board.
 5  #define PAD0Mask (1U << PAD0)
 6  int main ()
 7  {
 8    DIRA = 0;
 9    OUTA = 0;
10    DIRA |= LED0Mask ;
11    OUTA |= LED0Mask ; // illuminate LED0
12    while (1) {
13      waitcnt (CNT + CLKFREQ /10) ; // don 't do this too ↵
        quickly ...
14      DIRA |= PAD0Mask ; // set to output
15      OUTA |= PAD0Mask ; // set pad0 high
16      DIRA ^= PAD0Mask ; // set pad0 back to input
17      waitcnt (CNT + CLKFREQ /1000) ;
18      if (INA & PAD0Mask) // still high - no touch
19        continue ;
20      OUTA ^= LED0Mask ;
21    }
22  }
```

- **Lines 8–11**: Set the output state register OUTA and the direction register DIRA to illuminate the LED.
- **Lines 13–15**: Set the pad 0 pin to output, raise it high, and set it back to input.
- **Lines 16–19**: Wait 1ms and check the value of the pad 0 pin. The INA register bit 0 will reflect the value of pin 0. Thus, if pad 0 is high (not touching the touchpad), then bit 0 of INA is high, the AND will return TRUE, and the loop will continue without changing the LED. If pad 0 is low (you touched the touchpad), the AND will return FALSE and the next statement toggling the LED will be executed instead.

15.4 Implementing SPI in Cog-C

Let's implement the SPI protocol in Cog-C. The main cog will start two cogs: an SPI master and an SPI slave. The master cog will request a long of data from the slave and store it to a shared array. The slave cog will wait for a request and transmit a number (our fake data is zero the first time and increments by one for each request).

In SPI, communication is controlled by the master, which asserts (lowers) the chip select (`CS`) line and then transmits a clock (`CLK`). The master reads the `MISO` (master in, slave out) line at the rising edge of the clock (see Figure 15-2 for an example). The slave watches for the `CS` line to go low and must place data on the `MISO` line before the rising edge of each clock cycle. We will use 32-bit wide words, with the most significant bit (MSB) transmitted first.

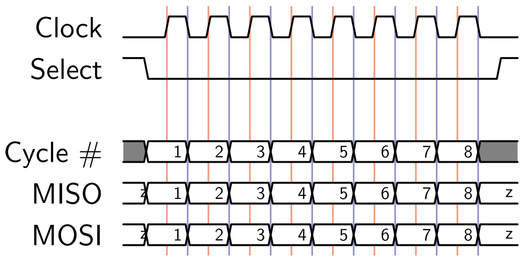


Figure 15-2. *SPI timing diagram for the case when the clock starts out low (CPOL=0) and the data is required to be valid on a rising edge (CPHA=0)*

15.5 Goals of This Chapter

In this chapter we will set all the necessary lines at the right times (and monitor and read them in the slave). We will exercise a number of ways of setting and reading particular bits in a number. In the next chapter, we will replace some of the "bit-twiddling" code with *inline PASM* to speed things up.

The structure of our project is as follows: a main cog will start two other cogs that communicate via SPI. The `spiSlave` stands in for a hardware device (for example, an analog to digital converter [ADC]) that produces data. The `spiMaster` will read data from the `spiSlave` and store it in the array `data`, which will be read by the main cog.

The main/controller cog and the SPI master cog must coordinate their access to the data array. We will use a *lock* to signal between `main` and `spiMaster` that the `data` array is either being filled with data by `spiMaster` or ready for processing by `main` (see Figure 15-3 for a diagram illustrating this process).

Create a new project called `spi-c` with four files: `spi-c.c`, `spi-c.h`, `spiMaster.cogc`, and `spiSlave.cogc`.

Because the SPI master and slave are `.cogc` files, they will be placed entirely in cog memory.

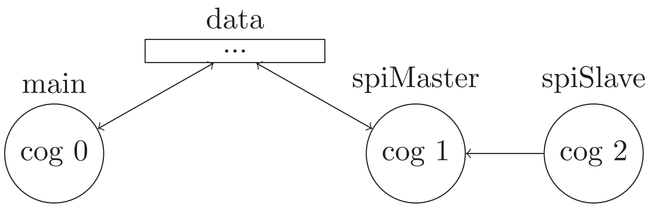


Figure 15-3. *Structure of the SPI program*

15.5.1 Main Cog (Controller)

The main cog will control the other cogs. It will launch the SPI master and slave and process the data that the master receives from the slave. The data will be stored in a shared memory array called `data[]`. To ensure that the main cog knows when the master is done populating the data array, we use a lock (semaphore). Listing 15-4 has the contents of the main file, which will start up two cogs (the master and the slave) and print the contents of the data array once the master has received all the data from the slave.

Listing 15-4. Contents of Main File spi-c.c

```
#include <stdio.h>
#include <propeller.h>
#include "c-hw.h"

struct cogmem_t {
  unsigned int stack [50];
  volatile struct locker_t locker ;
};

/* reserve memory for spimaster cog and spislave cog */
struct cogmem_t mcogmem ; // master
struct cogmem_t scogmem ; // slave

/* functions to start cogc cogs */
int startSPIMaster (volatile void *p) {
  extern unsigned int _load_start_spiMaster_cog [];
  return cognew (_load_start_spiMaster_cog, p);
}
int startSPISlave (volatile void *p) {
  extern unsigned int _load_start_spiSlave_cog [];
  return cognew (_load_start_spiSlave_cog, p);
}

/* shared memory with cogs */
volatile unsigned char masterSem ;
volatile int data [NSAMPS_MAX];

int main ()
{
  int masterCogId, slaveCogId, i;
  unsigned int t0;

  masterSem = locknew ();
  while (lockset (masterSem)) {;} // obtain lock

  /* start both cogs */
  masterCogId = startSPIMaster (&mcogmem.locker);
  slaveCogId = startSPISlave (&scogmem.locker);

  printf (" master id = %d slave id = %d sem = %d\n", ➥
  masterCogId, slaveCogId, masterSem);
  t0 = CNT ;

  lockclr (masterSem); // release lock, spimaster obtains lock
  // wait for spimaster to release lock,
  while (lockset (masterSem)) {;}
  t0 = CNT - t0;
  printf (" Time to read 128 longs = %d\n", t0);

  // process array
  for(i=0;i< NSAMPS_MAX ;i++)
    printf ("i=%d data =%x\n", i, data [i]);

  DIRA |= LED0Mask ;

  while (1)
  {
    OUTA ^= LED0Mask ;
  }
}
```

- **Lines 5–12**: We define a `struct cogmem_t` with space for the stack and a dummy entry for the locker (the `PAR` locker is unused because we use shared global memory). We declare and reserve memory for the two cogs as `mcogmem` and `scogmem`.
- **Lines 15–22**: Functions to start the master and slave cogs.
- **Lines 25–26**: Shared global memory. The `masterSem` is where the lock (semaphore) is stored that will be used by the main cog and the SPI master to control access to the data array. The data array is simply, and with great originality, named `data[]`.
- **Lines 33–34**: Create a new semaphore and obtain the lock in the main cog. Thus, when we start the SPI master cog, it will sit idle attempting to obtain the lock.
- **Lines 37–38**: Start the two SPI cogs.
- **Line 43**: Release the Kraken. Upon main releasing the lock, the SPI master will obtain it, which will start a data acquisition cycle. During this time, the main cog should not touch the data array.
- **Line 45**: Continuously attempt to obtain the lock. Only once the SPI master has completed a data acquisition cycle will it release the lock, allowing the main cog to proceed beyond here.
- **Lines 50–51**: "Process" the data; print it out.

The header file (Listing 15-5) contains the pin definitions for the SPI transfer as well as a dummy locker definition (we don't use the `PAR` locker; rather, we prefer to use shared memory).

Listing 15-5. Contents of Header File spi-c.h

```
#define NSAMPS_MAX 128

#define LED0 16
#define LED0Mask (1U << LED0)

#define CS 10
#define CLK 11
#define MOSI 12
#define MISO 13
#define CSMask (1U << CS)
#define CLKMask (1U << CLK)
#define MOSIMask (1U << MOSI)
#define MISOMask (1U << MISO)

struct locker_t {
};
```

15.5.2 SPI Master

The SPI master (Listing 15-6) begins by setting the SPI pins `CS`, `CLK`, and `MOSI` as outputs. The `CS` line idles high and is active low, so set it high before setting it as an output. Next, obtain the lock, which starts an acquisition cycle. Acquisition consists of lowering the `CS` line and then clocking out 32 cycles on the `CLK` line. At each rising edge of `CLK`, read the value of the `MISO` and shift it into `val`. Finally, place `val` into `data[]`. After `NSAMPS_MAX` acquisitions, release the lock.

Listing 15-6. Contents of spiMaster.cogc

```
#include "c-hw.h"
#include <propeller.h>

extern unsigned char masterSem ;
extern int data [NSAMPS_MAX];
void main (struct locker_t *p) {
  int i, j, val, bit ;
  int clkwidth =50;

  // init SPI pins
  OUTA = 0;
  OUTA |= CSMask ; // preset CS high
  DIRA = 0;
  DIRA |= CSMask | CLKMask | MOSIMask ; // set to outputs

  while (1) {
    while (lockset (masterSem)) { // wait to obtain lock
      ;
    }
    // read from spi and write to data []
    for (i=0; i< NSAMPS_MAX ; i++) {
      OUTA ^= CSMask ; // lower cs
      val = 0;
      for (j =31; j >=0; j --) {
        waitcnt (CNT + clkwidth); // wait
        OUTA ^= CLKMask ; // raise clock

        // get value of miso pin and put in low bit
        bit = (INA & MISOMask) >> MISO ;
        // shift bit into val
31          val |= bit << j;
32          waitcnt (CNT + clkwidth);
33          OUTA ^= CLKMask ; // lower clock
34        }
35        data [i] = val ;
36        OUTA ^= CSMask ; // raise cs
37        waitcnt (CNT +3* clkwidth);
38      }
39
40      lockclr (masterSem); // release lock
41    }
42  }
```

- **Lines 4–5**: The shared global memory is referenced with the `extern` keyword.
- **Line 8**: We include a short delay between clock transitions so that the SPI master and slave have enough time to read and write the bit. This is generally specified by the device. Here I set it as low as I could and not corrupt the data (I did this by trial and error).
- **Lines 11–14**: Set `CS` high by setting that bit of `OUTA` to 1. Set `CS`, `CLK`, and `MOSI` as outputs by setting those bits of `DIRA` to 1. (`MOSI`—master out, slave in—is unused here but could be used to transmit data to the slave.)
- **Line 17**: Wait here until the lock is obtained. `masterSem` is shared from the main cog.
- **Lines 21–38**: Acquire `NSAMPS_MAX` samples.
- **Line 22**: Lower the `CS` line by performing an exclusive OR of `OUTA` with `CSMask`. We already set the `CS` bit of `OUTA` high, so the XOR will lower it.

- **Lines 24–24**: Loop over the 32 bits, high bit to low bit.
- **Lines 26 and 29**: Raise the CLK line and read the value of MISO pin in the INA register. Shift it right by MISO places so that the variable bit contains either a 0 or a 1 in the lowest bit location.
- **Line 31**: Now shift the low bit of the variable bit left by 31, 30, …, 0 bits into val.
- **Line 33**: Lower the clock line and repeat.
- **Lines 35 and 36**: Place the number val into data[] and raise the CS line, ending the acquisition of the i-th number.
- **Line 37**: Introduce a delay between acquisition requests so the SPI slave can prepare for the next request.
- **Line 40**: Once all NSAMPS_MAX samples have been acquired, release the lock back to the main cog for it to process the data.

15.5.3 SPI Slave (Simulated Data Producing Device)

The SPI slave (Listing 15-7) stands in for a data acquisition device or digitizer. It will wait for the CS line to go low and then place the MSB of its “data” on the MISO line. Once it sees the CLK line go high and low, it is free to put the next bit on the MISO line. Rinse and repeat 32 times.

Listing 15-7. Contents of File spiSlave.cogc

```c
#include "c-hw.h"
#include <propeller.h>

static _COGMEM int val ;
static _COGMEM int j;
static _COGMEM int bit ;
void main(struct locker_t *p) {
  int i=0;
  DIRA = 0;
  OUTA = 0;
  DIRA |= MISOMask ;

  i=0;
  while (1) {
    val = i;
    waitpeq(CSMask, CSMask);
    waitpne(CSMask, CSMask);
    for (j =31; j >=0; j --) {
      bit = (val >> j) & 0x01; // get jth bit
      OUTA ^= (- bit ^ OUTA) & MISOMask ; // set miso pin of outa to bit
      waitpeq(CLKMask, CLKMask); // wait for rising clock ...
      waitpne(CLKMask, CLKMask); // and then falling clock
    }
    OUTA &= ! MISOMask ; // lower miso line
    i++;
  }
}
```

- **Lines 4–6**: `static _COGMEM int val` will ensure that the variable `val` is stored in cog memory (like a `val long 0` expression in PASM) rather than being stored in hub memory. This will speed up use of that variable because hub access is slower than cog memory access.
- **Line 11**: Set the `MISO` line as an output.
- **Lines 16–17**: Ensure that the `CS` line is high and then that it is low. This high-to-low transition signals the start of an SPI data transmission cycle.
- **Lines 19–20**: `val` is the value to be transmitted to the SPI master. Get the `j`-th bit (starting at the most significant bit).
- **Line 20**: This mysterious concoction sets the bit in `OUTA` that corresponds to the high bit of `MISOMask` to the value of `bit`. I stole it from `http://graphics.stanford.edu/~seander/bithacks.html`.
- **Line 21**: Wait for the rising clock. In the previous line I set the `MISO` line to bit `j` of `val`, and on the rising clock the SPI master will read that bit value.
- **Line 22**: Wait until the clock goes low. The `MISO` line must hold the `j`-th bit throughout the time the clock is high to allow the SPI master time to read it. Once the master lowers the `CLK` line, the slave is free to move on and put the next bit on the `MISO` line.
- **Line 24**: After all 32 bits have been transmitted, clear the `MISO` line (which is not strictly necessary).

15.5.4 Running the SPI Code

Let's run the code.

```
master id = 1 slave id = 2 sem = 1
Time to read 128 longs = 623664
i=0 data=0
i=1 data=1
i=2 data=2
... lines deleted

i=127 data=7F
```

We successfully acquired 128 32-bit samples and processed them. It took about 623,000 counts, or 7.8ms, to acquire those samples (this board has an 80MHz clock). Thus, the data transfer rate is 128 samples × 32 bits/7.8ms ~ 0.525Mb/sec.

In the next chapter, we will try to speed that up by using *inline assembly instructions*.

15.6 Summary

We can access all the same registers as in Spin or PASM. In particular, we can write to the `outa` and read from the `ina` registers thusly (Listing 15-8):

Listing 15-8. A C language template for setting and reading a pin

```
#define INPIN 0
#define OUTPIN 16

int main() {
  const inPinMask =(1U << INPIN);   // create masks with pin position = 1
```

```
 const outPinMask =(1U << OUTPIN);
 int i, inVal ;

 DIRA |= outPinMask ;  // set the direction for OUTPIN to output
 DIRA &= ~inPinMask ;  // ... and the directino for INPIN to input

 for (i=0; i <10; i++) {
  waitcnt (CNT + CLKFREQ);  // access the CNT register and the CLKFREQ value
  OUTA ^= outPinMask ;      // toggle the OUTPIN value
  inVal = (INA & inPinMask) >> INPIN ;  // read the INPIN value
  printf (" inVal = %d\n", inVal);
 }

 while (1) {
  waitpeq(inPinMask, inPinMask);  // wait for INPIN to be high
  printf(" switch pressed ...\ n");
  waitpne(inPinMask, inPinMask);  // ... and low
  printf(" switch released ...\ n");
}
```

Here are some valuable fragments of C code:

```
bitValue = 1;
mask1 = (1U << bitPosition1 )
mask2 = (1U << bitPosition2 )
reg |= mask1 ; // set a bit at bitPosition1

```

```
// set a bit in reg at bitPosition1 and bitPosition2
reg |= ( mask1 | mask2 );
// clear the bits at bitPosition1 and bitPosition2
reg &= ~( mask1 | mask2 );
reg ^= mask1 ; // toggle the bit at bitPosition1

// set the value of the bit at bitPosition1 in variable
// reg to the value of bitValue
reg ^= (- bitValue ^ reg) & mask1 ;

// read the value of the bit at bitPosition1 of variable reg
bitValue = (reg & mask1 ) >> bitPosition1 ;

// shift the value of bit 0 of bitValue into reg
reg = (reg << 1) | ( bitvalue & 0x01)
```

There is no equivalent to the sar (or “shift arithmetic right”) instruction whereby when you shift right and the high bit is copied into the shifted positions. Rather, we must use a C construct known as a *bitfield*.

```
// Spin or PASM :
// i := $FF ' i is %00000000 _00000000_00000000_11111111
// i <<= 24 ' shift left by 24 bits
// now i is $FF_00_00_00 or %11111111 ↩
_00000000_00000000_00000000
// i ~>= 24 ' shift arithmetic right by 24 bits
// now i is $FF_FF_FF_FF or %11111111 ↩
_11111111_11111111_11111111

// C:
int i, signExtendi ;
i = 0xFF;
```

```
// i is %00000000 _00000000_00000000_11111111,
// which is i =255 if treated as a 32 bit number,
// but i=-1 ** if treated as an eight -bit number **
// we would like to set signExtendi to be a 32 bit value equal to -1
//
// One can inform C of the bit - size of a number by creating a
// struct with a field that has a ":8" (for an eight bit number)
struct signExtend8 {
   signed int x :8; // the :n can be any number ...
} s8;

// we assign our signed eight bit number 0 x000000FF to the bitfield
s8.x = i;
// ** when we ask for it back and want it written to a 32 bit number, the
// compiler knows to sign extend it properly **
signExtendi = s8.x;
// now signExtendi = 0 xFFFFFFFF
```

CHAPTER 16

Using Inline Assembly Instructions in C Code

Let's now look at using PASM and C in the same stretch of code using a technique called *inline assembly*. You can use this when you require the fastest possible execution of a small section of repeated code. The main part of the code remains in C, but the critical section is written in PASM. In Figure 16-1, there is a drawing of the Antarctic Snow Cruiser: a hybrid exploration vehicle that was ahead of its times.

In this example, we will read the input pin `MISO` 32 times and shift the value into a variable called `val`. This is done in SPI (see the previous chapter) where data is transferred serially, one bit at a time.

Here is how we did it in C:

```
// get value of miso pin and put it in low bit
bit = (INA & MISOMask) >> MISO ;
// shift bit into val
val |= bit << j;
```

If we were to do this in PASM, we would use the following instructions:

```
test ina, misoMask wc ' set C to the miso pin value
rcl val, #1           ' rotate val left and set LSB to C
```

The PASM code is faster because there are only two instructions to perform, but the C code has six: the AND of `INA` and `MISOMask`, the right shift by `MISO` bits, the assign to `bit`, the assign to `j`, the left shift by `j`, and the OR with `val`.

We can *inject* the PASM instructions into the middle of the C code to improve performance, as shown in Listing 16-1.

Listing 16-1. Modified Version of spiMaster.cogc That Uses Inline Assembly

```
 1  ...
 2
 3          // get value of miso pin and put in low bit
 4          // bit = (INA & MISOMask) >> MISO ;
 5          // val |= bit << j;
 6          __asm__ (
 7            " test %[mask], ina wc\n\t"
 8            "rcl %[val], #1\n\t"
 9          : // outputs
10            [val] "+r" (val)
11          : // inputs
12            [mask] "r" (mask)
13            );
14          ...
```

- **Lines 4–5**: The commented-out C version of reading `MISO`.
- **Lines 6–13**: The inline assembly *injection* of the two PASM instructions.

16.1 Inline Assembler

Let's try to decode that gobbledygook!

The inline assembly has the pattern shown in Listing 16-2.

Listing 16-2. Inline Assembly Format

```
__asm__ (
  "<pasm instruction>"
  "<pasm instruction>"
: <output variable>,
  <output variable>
: <input variable>,
  <input variable>
);
```

PASM instructions are standard instructions, with one difference: any variables you want to use in the instruction are referred to as `%[<varname>]`. These variables can be shared with the C code. This is done via the output and input sections (after the colons). Each PASM instruction is enclosed in quotes. Successive PASM instructions should not have commas, but they can be on different lines.

You can have more than one input/output variable separated by commas. Let's look at lines 7 and 8 in Listing 16-1 in detail.

- `test ina, %[miso] wc: test` is a PASM instruction with two arguments, and we specify a `wc` effect. What it does is compare the bit of `miso` that is high (bit 12) with `ina` and set the `C` flag to 1 if `ina` is 1. The expression `%[...]` will refer to the variables named in the input and output sections.

- `rcl %[val], #1` will shift the variable `val` left by 1 bit and will shift `C` into bit 0.

The variables `%[miso]` and `%[val]` refer to the variables `miso` and `val` in the C code because of these statements (lines 10 and 12 of Listing 16-1):

- `[val] "+r" (val)`. This says the variable `val` in the C code should be given the name `val` in the PASM code so that PASM instructions can refer to `%[val]`. The `"+r"` says that this is both an input variable and an output variable. It is modified inside the PASM instructions, and then that modified value is available to the C code.
- `[miso] "r" (miso)`. The `"r"` says that `miso` is solely an input variable and isn't modified in the PASM.

You can refer to the variables by different names in C and in PASM, but why complicate things? (The C variable name is to the right of `"+r"` in parentheses, and the PASM variable name is to the left of `"+r"` in square brackets.)

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RAYMOND J. BROWN, Editor

Planting the Stars and Stripes in the Antarctic

CRUNCHING snow and ice beneath ten-foot pneumatic tires, throbbing with the combined 400 horsepower of its mighty Diesel engines, a fifty-five-foot juggernaut with a swift airplane poised on its broad back soon will roll into polar lands of mystery. As fantastic a land craft as the strangest creations of fiction, this "snow cruiser" heads an array of scientific innovations that will serve the forthcoming U. S. Government expedition to Antarctica and the South Pole.

Scheduled to start early in October, the expedition marks the first official step to take possession, by actual occupation, of the vast sectors of the polar continent claimed for this country by Lincoln Ellsworth and Rear Admiral Richard E. Byrd. Its explorations may also strengthen long-pending U. S. claims to other areas first sighted by pioneer American explorers in the Antarctic.

Spurred by the increasing number of claimants to slices of the antarctic "pie," which now include Argentina, France, Germany, Great Britain, and Norway, Congress voted initial funds of $340,000 for the project last June. The result is a newly created

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Figure 16-1. *Antarctic Snow Cruiser. A hybrid tractor, tank, laboratory, and aircraft carrier for Antarctic exploration intended for use by Admiral Byrd in 1939. Alas, its weight was too much for the snow surface, and it was never used. Popular Science Monthly, v. 135, no. 5, Nov., 1939.* http://bit.ly/2eJOofM*: public domain.*

16.2 spiSlave.cogc Inline Assembly

The `spiSlave.cogc` C code can also be modified to use inline assembly, as shown in Listing 16-3.

Listing 16-3. Modified Version of spiSlave.cogc to Use Inline Assembly

```
1  ...
2      // bit = (val >> j) & 0x01 ; // get jth bit
3      // OUTA ^= (-bit ^ OUTA ) & MISOMask ; // set miso pin ↩
       of outa to bit
4      __asm__ (
5        "shl %[val], #1 wc\n\t"
6        " muxc outa, %[mask]\n\t"
7      : // outputs (+r) for inputs
8        [val] "+r" (val)
9      : // inputs
10       [mask] "r" (mask)
11     );
12 ...
```

- **Lines 2–3**: Commented-out C code that set the `MISO` pin.
- **Lines 4–11**: Injected PASM code to replace the C code.
- **Line 5**: `shl %[val], #1 wc` will set `C` to the most significant bit of `val`.
- **Line 6**: `muxc outa, %[mask]` will set `outa` to the value of `C` at those bit locations specified in `mask`.
- **Line 8**: `val` is a C variable that will be modified by PASM instructions.
- **Line 10**: `mask` is an input variable only; it isn't modified here.

16.3 Timing

Running this version of the code results in the following:

```
master id = 1 slave id = 2 sem = 1
Time to read 128 longs = 334128
i=0 data=0
i=1 data=1

...
```

This is about twice as fast as the C version.

16.4 Summary

The ability to *inline PASM code* brings an impressive increase in speed while still allowing us to use regular C code for the majority of the work. To use this technique, include an assembler directive at the location where the time-consuming (or bit-twiddling-intensive) code is present.

```
...
// c code here
int i, j;
i = 12;
__asm__ (
  "mov %[j], %[i]\n\t" // the \n is needed to separate the
  "add %[j], #42\ n\t" // two instructions. The compiler ↩
                          copies these
                       // verbatim and without the \n it ↩
                          would see
                       // ``mov j, iadd j, #42''
                       // which is a nonsense instruction
: /* output variable j is modified in the asm */
```

```
  [j] "+r" (j)
: /* input variable i is not modified */
  [i] "r" (i)
)
// c code continues
// here, i is still 12, but j = 54
```

CHAPTER 17

Concluding Thoughts

This book has just skimmed the surface of the capabilities of the Propeller microcontroller.

As always, the best way to learn is by doing, so pick a problem of interest and have at it. The next best way to learn is to study somebody else's code. You can download a number of Spin and PASM projects at the Object Exchange (`http://obex.parallax.com`).

There are a number of programs already written in Spin, and there is a large knowledge base available to help with learning it and fixing problems. However, Spin is relatively slow. Furthermore, Parallax is encouraging new users to learn to use C to program the Propeller and encouraging existing users to migrate. There is a huge knowledge base of information on "standard" C, but the Propeller-specific parts of C are still in development. Finally, PASM is by far the fastest way to run your code (particularly for bit-twiddling), but Cog-C mode is nearly as fast (see Table 17-1).

Table 17-1. *Comparison of Compression Speeds*

Language	Number of Counts to Compress 128 Samples
Spin code	1.5 million counts
C code (LMM only)	150,000 counts
Cog-C mode	42,000 counts
Mixed-mode C and PASM	23,000 counts
PASM code	22,000 counts

The ideal combination may well be C with Cog-C modules and injected inline assembly code for particular tasks. This is also, unsurprisingly, somewhat complex. I hope that you can use the examples in this book to do your own projects. Good luck with your journey (Figure 17-1)!

Our motto might be "Render unto C that which is C's and unto PASM to twiddle bits!"

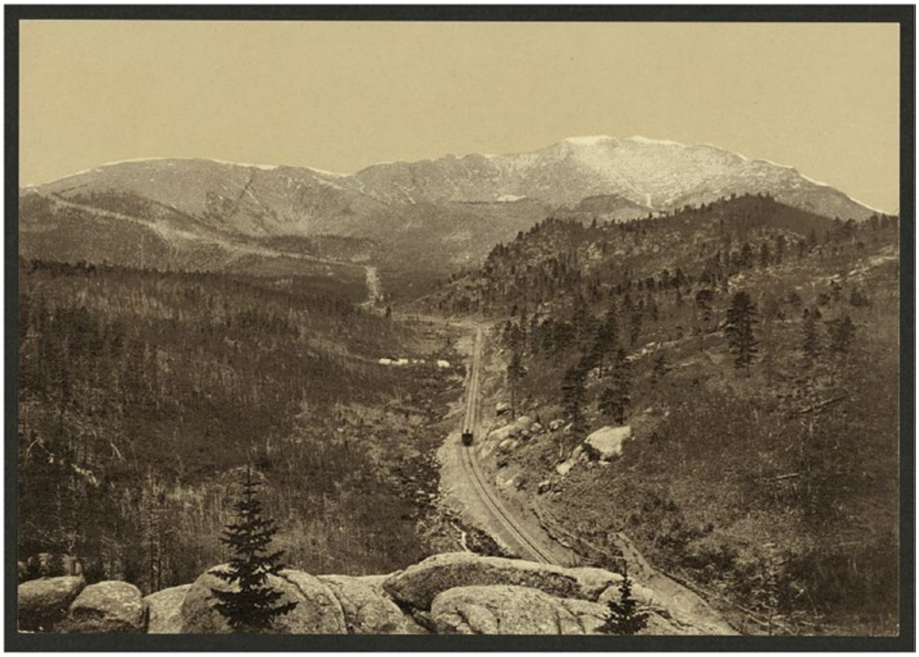

Figure 17-1. *Crossing the timber line, Pike's Peak Railway, some time between 1898 and 1905. Detroit Photographic Company, public domain.* `https://goo.gl/dzvSXN`.

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