The Computer Applications Platform, 0th Edition

December 2010

Contents

Chapter 1

Manifesto, Structure, Functions, Objects

This is the description of `cap` – a Computer Applications Platform. Here is one way to build all the software needed to use a computer including that which is traditionally termed the compiler, the operating system, applications and documentation.

Here is also a process for building software that is intended to be easy to maintain and extend, describe and distribute. As a manifesto for holistic coding, tenets of practice are introduced within the document at points where they are demonstrated.

manifesto

To promote understanding, `cap` is a literate program[1] wherein regular descriptive text (such as this paragraph) is mixed with computer evaluated program text in a `monospace font`.

literate programming, program text

Tenet the First: The Documentation and the Code are One.

Finally, it is hoped that `cap` embodies a pleasant system to use for general computing tasks.

[1] Donald E. Knuth, Literate Programming, Stanford, California: Center for the Study of Language and Information, 1992, CSLI Lecture Notes, no. 27

1.1 Requirements

Requirement — Track Requirements. 01/01/2009 ✓

requirements

When goals (or requirements) are determined at the outset of a project, progress is tracked, and fulfillment is tested, a project is more likely to be successfully completed more quickly and with greater assurance of satisfactory execution than it would be without establishing and tracking requirements[2].

In `cap` the requirements are explicitly included, tracked, and tested or acknowledged as having been met from within the literate programming text of `cap` (this document).

The requirements mirror the organizational structure as each chapter, section, and subsection provides functionality needed by the system. Section requirements are found at the beginning of the section. Goals for the whole project are listed here:

Requirements for the Computer Applications Platform

Requirement a — Provide functionality comparable to the compiler, operating system, and applications of a conventional platform used for general computing tasks. unmet

Sub-requirements specify specific goals that must be met to satisfy the main requirement, such as:

Requirement a.1 — Execute on conventional hardware. unmet

A maximally useful system will run on easily acquired computers.

Requirement a.2 — Re-create own executable structure from source text. unmet

The system should be self-reliant for its own development. The above requirement also captures the functionality of the typical compiler in existing systems.

Requirement a.3 — Provide operating system features such as process isolation, scheduling, storage and retrieval, internetworking, input/output, and computer resource management. unmet

[2]Barry W. Boehm, A Spiral Model of Software Development and Enhancement., ACM SIGSOFT Software Engineering Notes 11, 1986

The above requirement encapsulates operating system activities.

Requirement a.4 — Build and execute additional programs from additional source texts.	unmet

The above requirement provides for the development of applications for the system.

Requirement a.5 — Safely execute machine code compiled by other systems.	unmet

CAP may not be the best tool with which to create a particular application. The system should interoperate gracefully with other programming tools and systems.

Requirement b — Demonstrate holistic coding.	01/23/2009 ✓

The incorporation and incremental development of software development[3] extrinsic aspects that can be captured in document form is called holistic coding in `cap`. The requirements of a project are one such aspect.

holistic coding

Tenet the Second: Code Holistically.

Requirement b.1 — Produce documentation, including a summary of requirements and project status from the source text.	unmet

The above requirement integrates documentation of the system with the system.

Requirement b.2 — Integrate defect tracking, unit tests, regression tests, and a summary of test results with the source text.	unmet

Thorough testing reduces the number of programming defects (bugs) in a system. Testing and defect tracking is another extrinsic that is folded into the `cap` source text in adherence to holistic programming principles.

Requirement b.3 — Integrate version and revision control as well as software distribution with the source text.	unmet

Another common extrinsic to larger software projects is that of version and revision control, as well as packaging and distribution of the system and its

[3] Frederick P. Brooks, Jr., No Silver Bullet, 1986

applications and components. The `cap` system should internalize these aspects of software development and use.

One programming task often overlooked and then attempted in an ad-hoc manner is that of adapting a program or system to other languages and locales than it was initially developed in. `cap` itself should be easily translated and localized, and it should extend the same flexibility to other program texts written in the same way.

Requirement c — Instrument source texts for localization and internationalization. unmet

The preceding requirements outlined in boxes in this section (1.1) are requirements for the system as a whole but they are not all of the requirements for `cap`. Like any large project this effort has been subdivided into smaller parts so that the system may be developed incrementally. Each chapter, section, and subsection is devoted to a specific aspect of `cap` functionality and contains its own requirements, and those requirements taken all together form a complete set which is listed in Appendix I.

The requirements, the code, and the chapters and sections of explanatory text are all developed incrementally and together, with later chapters and sections building on features and concepts introduced in earlier chapters and sections. Requirements, tests, and other extrinsic matters of software development are introduced in the text where they are relevant but may also be summarized elsewhere and expanded upon later in the text. This incremental method of development is intended to make the entire system easier to understand and maintain.

Tenet the Third: A Bit at a Time.

1.2 License

Requirement — Select License. 01/23/2009 ✓

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1.3 Project and Sub-Project Status

Requirement — Track Project Status. 01/01/2009 ✓

A large project benefits from being broken down into manageable sub-projects. In `cap` each sub-project has its own chapter and each chapter provides concepts and features that the next chapters may build upon.

The complete Computer Applications Platform 0th edition will be presented in the following chapters, including sub-sub-projects and requirements met:

Chapter:		Page — ssp — req
One	Manifesto, Structure, Functions, Objects.	5 — 3/8 — 1/11
Two	The Syntax of Syntax.	47 — 0/4 — 0/9
Three	Kernels and Runtimes.	61 — 0/4 — 0/5
Four	Documents.	63 — 0/4 — 0/0
Five	User Interface.	65 — 0/4 — 0/0
Six	Networking `cap`.	67 — 0/4 — 0/0
Seven	Applications for the Computer Platform.	69 — 0/4 — 0/0
Eight	Distributing the System.	71 — 0/4 — 0/0
Nine	Adapting to the World.	77 — 0/4 — 0/0
Appendix I	Requirements.	79 — — — — —
Appendix II	Additional Architectures.	73 — 0/4 — 0/0
Appendix III	Log of Changes From The Previous Edition.	75 — — — — —

Sub-Projects (chapters) for CAP 0th edition.

This document incrementally presents both the abstract concepts of cap and also the concrete realization of cap, with the most fundamental concepts coming first, and also with the most basic realized constructs before later more complex ones. The dualism of abstract concepts on the one hand and concrete constructs on the other will be explored throughout this document. The structure of this book and also of this chapter reflects just such a decomposition of the complete whole.

This chapter has the following sections (asterisk indicates sub-sub-project:)

Sub-projects (sections) for Chapter 1: Manifesto, Structure, Functions, Objects.

1.4 Structure, Syntax, and Values

Requirement — Provide Fundamental Structure. 07/01/2008 ✓

structure, tree

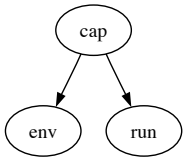
The structure[4] of the Computer Applications Platform can best be understood as a conceptual tree[5] with the label `'cap'` at the root and with the branches of the tree being subsystems, subcomponents, resources, etc.

> Tenet the Fourth: There Is But One Tree.

names, programs

`cap` at the root names[6] the system as a whole. There are two branches to the tree to start with: an environment of programs and resources for programs[7] to use and also a set of programs operating in that environment. The program text below introduces the names `env` for environment and `run` for executing or dormant programs. To the right of the program text is a diagram showing the abstract tree structure created by it.

```
‘cap ~ (  [ env :~ $ ];
          [ run :~ $ ];
            $ );
```



code, syntax, definition,

The above code[8] presumes a syntax[9] . The syntax shown is that of the `i` incremental programming language. See Syntax Guide to i Code on the next page for an introduction to the meanings of the symbols in the above code.

nodes, abstract syntax tree, extension

The effect of processing the above code is the insertion of new nodes containing names and other attributes in a tree initially having just one node (simply labeled `cap` .) This forms an conceptual tree which in some systems is referred to as an abstract syntax tree.

The syntactic feature of leaving a definition open to extension and then later

[4] Harold Abelson, Gerald J. Sussman: Structure and Interpretation of Computer Programs, Second Edition MIT Press 1996

[5] Donald E. Knuth, The Art of Computer Programming, Volume I: Fundamental Algorithms, 1968, Addison-Wesley, pp. 309-310

[6] Joe Lykken, What's in a name?,Symmetry Magazine, Volume 2 Issue 2 March 2005

[7] N. Wirth, Algorithms + Data Structures = Programs, Prentice Hall, 1975

[8] a.k.a. program text

[9] Roland Carl Backhouse: Syntax of Programming Languages: Theory and Practice Prentice-Hall 1979

extending it is a way to present information in an order for better explanation (pedagogical order) instead of linear program order. For example, the code introduces a place for language definitions (`lang`) within the environment and also leaves room for more environment definitions without specifying them yet:

```
‘cap,env ~ (  [ lang :~ $ ]; $ );
```

Syntax Guide to i Code

Definitions come wrapped in square brackets, e.g.

```
[ something ];
```

A colon and a tilde separate the name of the new thing from its contents, which may be references to things previously defined. Also, the name of a thing can be made of multiple words separated by white space.

```
[ a thing encompassing :~ something ];
```

Semicolons separate multiple content items, and multiple items within the contents of a definition are grouped by parentheses.

```
[ apple ];
[ pear ];
[ kiwi ];
[ fruit basket :~ ( apple ; pear; kiwi ) ];
```

The contents of a definition may be marked by a dollar sign indicating that the content will be filled in later.

```
[ picnic table :~ $ ];
```

A back-tick and a previously-defined reference indicate that a previously marked location is now being filled in. If it is filled in with multiple items then parentheses are needed. The last item may be a dollar-sign marker for later expansion.

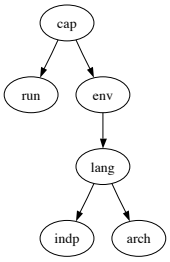
```
[ bottle of wine ];
‘ picnic table ~ (fruit basket; bottle of wine; $);
```

Definitions may be placed within the content area of other definitions or extension to definitions.

i syntax.

architecture dependence and independence

The Computer Applications Platform is intended to run on many different types of computers which may differ in how they operate at a low level such as their machine code or collection of attached devices. Computers in general function similarly as they are all stored program machines with memory, one or more computational units, and some form of input and output. In `cap` aspects of the system that are dependent on the architectural details of the host computer are placed in the `arch` branch of the tree and aspects of the system that are common across architectures can be found in the `indp` branch.




```
‘cap,env,lang ~ (
  @[ indp :~ $ ];
  @[ arch :~ $ ];
  $ );
```

values, byte order

The three snippets of `cap` program code so far have only introduced abstract concepts and established structural relationships between them. In addition to abstract structure, definitions can introduce concrete values, which are stored in an 'image' which is kept separately. The most fundamental values are bytes and machine words of varying sizes. The concept of byte order, or endianness[10], is independent of processor architecture, and is defined next, in the branch of the tree for machine independent generation of machine code.

discontinuous, image

This next code section has more than just expansions of nodes as before (solid lines in the illustration.) It also defines nodes which refer to and include copied values of previously defined nodes (dashed line,) values for nodes (dotted line to a box,) nodes with no names but which define a type, extension of lexical scope (dotted line to an oval) and nodes that have types.

types

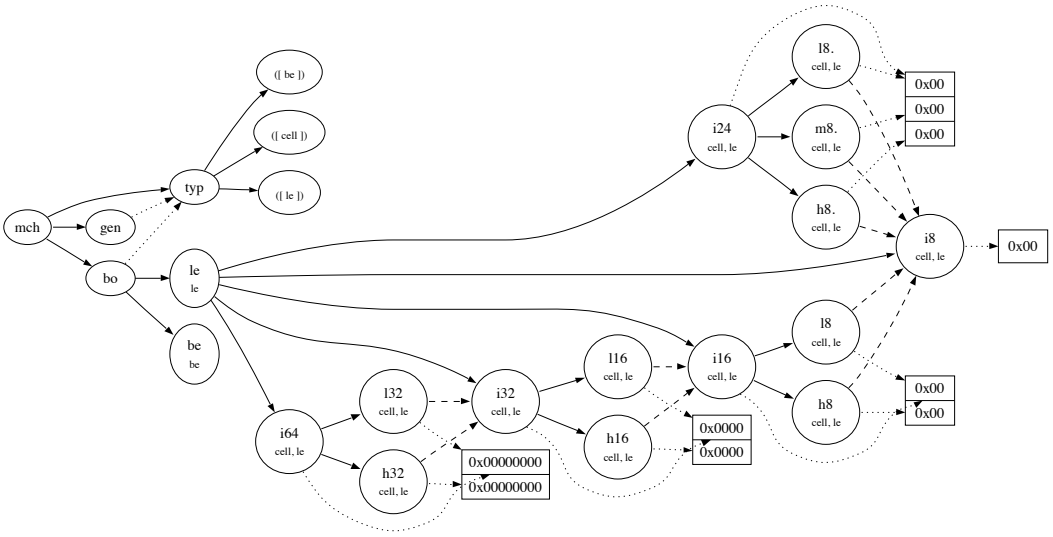
Types[11] are used in the `i` programming language to enable greater expressiveness in and increased safety for the system. The first types introduced in `cap` are for binary values stored in the system image.

The ovals in the figure represent nodes in the abstract syntax tree and square boxes represent image values. Contiguous storage of values is displayed as a 'stack' with the topmost value stored at the lowest memory address. The diagram shows that the values for i8, i16, i24, i32, and i64 are permitted to be

[10] Jonathan Swift,Gulliver's Travels and Other Works, Routledge, 1906
[11] Pierce, Types and Programming Languages, MIT Press

stored discontiguously from each other. bo stands for byte order, le stands for little-endian, and be stands for big-endian.

```
‘cap,env,lang,indp ~ (
 [ mch :~ (
  [ typ :~ (
    [:([cell:~])~];
    [:([be:~])~];
    [:([le:~])~])];
  [ gen :~ ( ^typ; $ )];
  [ bo :~ ( ^typ;
   [ le :le~ (
    @()[ i8  :cell:le~ 0x00 ];
    @()[ i16 :cell:le~ ([ l8 :~ i8 ]; [ h8 :~ i8 ])];
    @()[ i24 :cell:le~ ([ l8 :~ i8 ]; [ m8 :~ i8 ]; [ h8 :~ i8 ])];
    @()[ i32 :cell:le~ ([ l16 :~ i16 ]; [ h16 :~ i16 ])];
    @()[ i64 :cell:le~ ([ l32 :~ i32 ]; [ h32 :~ i32 ])])];
   [ be :be~ (
    @()[ i8  :cell:be~ 0X00 ];
    @()[ i16 :cell:be~ ([ h8 :~ i8 ]; [ l8 :~ i8 ])];
    @()[ i24 :cell:be~ ([ h8 :~ i8 ]; [ m8 :~ i8 ]; [ l8 :~ i8 ])];
    @()[ i32 :cell:be~ ([ h16 :~ i16 ]; [ l16 :~ i16 ])];
    @()[ i64 :cell:be~ ([ h32 :~ i32 ]; [ l32 :~ i32 ])])])];$)]);
 $ );
```



references, instances

When a previously defined item with a value or values is referenced for inclusion in a new definition (such as the two i16 values within an i32,) a new instance of those values is placed in the image at the new location. This is how `cap` builds binary objects that are the result of compilation in other systems. In some definitions only the sizes and offsets (relative to each other) of the values are important. In those cases the syntax directs the actual bit-patterns of the values to be disregarded when those definitions are referenced.

lexical scope

When a reference is made to previously defined constructs there may be more than one previously defined construct with that name (e.g. there are two definitions of i16 in the byte order code–one with a little-endian arrangement of its bytes, and the other with a big-endian arrangement of its bytes.) `cap` uses lexical scope[12] to manage the accessibility of items for reference.

import, promotion

For example, when defining the big-endian i32 the big-endian previous definition of i16 is naturally 'in scope' because it is a 'peer of a parent' when traversing back up the tree. The `i` syntax for lexical scope extension is used to bring the type definitions for cell, le, and be (and other types that will be defined later) into scope for the definitions of gen and bo.

[12] Harold Abelson and Gerald Jay Sussman, Lexical addressing, Structure and Interpretation of Computer Programs

Hexadecimal values can be introduced in the content area of a definition.

```
[ null byte :~ 0x00 ];
[ secret encryption key :~ 0X09F911029D74E35BD84156C5635688C0 ];
```

Hexadecimal values introduced with a lower-case x are stored in the image in little-endian format (least-significant-byte has the lowest memory address,) those with an upper-case X are stored in big-endian format.

```
[ big endian - the A1 byte comes first :~ 0XA1B2C3D4 ];
[ little endian - the d4 byte comes first :~ 0xa1b2c3d4 ];
```

Bare numbers up to 254 and down to -128 may be used and are bytes.

```
[ an unambiguous byte value :~ -4 ];
```

Types can be introduced in the type area of a definition. Also, definitions may be anonymous.

```
[:([ string ])~ ];
```

Simple ASCII strings (which are also values) can be introduced similarly. The definition may be assigned a type which was previously defined.

```
[ a greeting :  string ~ "hello" ];
```

An item by itself in the content area of a definition that begins with a character and does not match a previously defined item has the value of a short string.

```
[ an identical greeting :  string ~ hello ];
```

Values are placed in a binary image next to each other and the value of (and binary image space taken by) an encapsulating definition is the aggregate of the sub-definitions.

```
[ intl :~ [ phrases :~ [ greetings :~ (
[^ english greeting:  string ~ "Hello" ];
[^ german greeting:  string ~ "Guten Tag" ];
[^ french greeting:  string ~ "Bonjour" ])]]];
```

(intl now has the value "HelloGuten TagBonjour" which takes up 21 bytes).

A caret preceding a reference places definitions within the referenced item into the current scope for future references.

```
^ intl, phrases, greetings;
[ my null terminated string:([ cstring : ])~ ( french greeting; null byte ) ];
```

Definitions preceeded by an at-sign have values that are not required to be contiguous with siblings or the parent values.

```
@[ separate ];
```

Definitions preceeded by an at-sign and a null space specifier have values which are ignored on reference but which have offsets of interest.

```
@()[ data ];
```

i syntax, continued.

1.5 Machine Architecture and Machine Code

Requirement — Declare Machine Codes for Common Architectures. in process

The code in the previous section made increasingly refined divisions of abstract concepts moving from the general to the specific (e.g. from the `cap` system as a whole to the separation of architecture dependent from architecture independent constructs.) In addition it introduced the most basic concrete component with which the rest of the system is constructed: the byte, and then the larger cells that are assemblages of bytes.

instruction, routine

This section will continue the trend of refining the abstract, introducing machine architecture concepts such as registers, instruction formats, and routines, and also general computer programming concepts such as parameters, macros, compile-time calculation, and meta-circular definition. This section also will continue compounding the concrete by composing from bytes and words the actual machine code values for instructions and simple routines executable by real microprocessors.

Top Down, Bottom Up Programming

'Refining the Abstract' is another way of saying 'Top-Down Programming'. 'Compounding the Concrete' is another way of saying 'Bottom-Up Programming'. In cap both Top-Down and Bottom-Up programming styles are used at the same time but for different aspects of structuring the system. This section is decomposed into the following sub-sections:

1.5.1 *	Macro Expansion and Processor Registers.	18 - done
1.5.2 *	No Operation, Return, Clear Temporary.	20 - done
1.5.4 *	Jumps and Calls to absolute addresses.	21 - done
1.5.6 *	Relative Jump and Relative Subroutine Call.	25 - 0/8
1.5.8 *	Register Move.	26 - 0/8
1.5.9 *	Register Load / Store.	28 - 0/8
1.5.11 *	Register to Control Register.	30 — 0/8
1.5.12 *	Zero a Register.	31 - 0/8
1.5.13 *	Integer Math.	31 — 0/8
1.5.14 *	Stack Operations.	32 - 0/8
1.5.15 *	Load Register with Constant.	34 — 0/8
1.5.15 *	Compare Register Values.	34 — 0/8
1.5.15 *	Conditional Relative Branch.	34 — 0/8

Sub-projects (sub-sections) for Section 1.5.

1.5.1 Macro Expansion and Processor Registers

Requirement — Define CPU general purpose registers. 04/14/2009 ✓

Processor architectures[13] vary in many ways including how bytes are arranged in memory, how many registers they have, the format of and number of operations they perform –the machine code– and so on. This chapter prepares `cap` to support eight (or five) initial architectures:

processor architecture, machine code

```
‘lang,indp,mch,typ~([:([ cpu ])~];
                    [:([ yb ])~];
                    [:([ nb ])~]; $);
‘cap,env,lang,arch ~ (
  ^ lang,indp,mch,bo;
  @[ cpus  :~ ( x86l; x86m; x86s; armm; ppcl; ppcm; spkl; mmix ) ];
  @[ cpue  :~ (   le;   le;   le;   le;   be;   be;   be;   be ) ];
  @[ cpul  :~ (  b64;  b32;  b16;  b32;  b64;  b32;  b64;  b64 ) ];
  @[ cpuj  :~ (  b32;  b32;  b16;  b24;  b24;  b24;  b16;  b24 ) ];
  @[ cpurc :~ (   16;    8;    8;   16;   32;   32;   32;  256 ) ];
  @[ cpurb :~ (   yb;   nb;   nb;   nb;   nb;   nb;   nb;   nb ) ];
  $ );
```

While architectures differ in specific characteristics, in `cap` their definition follows a common format. `cap` exploits this common format and uses macro expansion of program text to avoid repetitive definitions that differ only in particulars.

macro expansion

The following macro is repeated once for each entry in 'cpus'. It creates within `arch` definitions which include in their scopes the branch of the AST reserved for machine-code generation definitions and also either the little-endian or the big-endian definition of memory cell byte order. Each is set to be expanded later with assembly language constructs for that architecture.

generator

```
‘cap,env,lang,arch ~ (
<: [ <. cpus, _ .> : cpu; <. cburb .> ~ ( ^ lang,indp,mch,gen;
                                          ^ <. cpue, _ .> ;  $ )]; :>
 $ );
```

The expansion macro is equivalent to but is more concise than the following:

[13] John L. Hennessy and David A. Patterson, Computer Architecture A Quantitative Approach, 1992

```
‘cap,env,lang,arch ~ (
      [ x86l : cpu; yb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,le ;  $ )];
      [ x86m : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,le ;  $ )];
      [ x86s : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,le ;  $ )];
      [ armm : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,le ;  $ )];
      [ ppcl : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,be ;  $ )];
      [ ppcm : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,be ;  $ )];
      [ spkl : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,be ;  $ )];
      [ mmix : cpu; nb ~ ( ^ lang,indp,mch,gen;
                           ^ lang,indp,mch,bo,be ;  $ )];
 $ );
```

From this point forward in this chapter, The following code sections are all expansions of the same `gen` portion of the tree, so the first line

```
‘cap,env,lang,indp,mch,gen~(
```

and the last line

```
$ );
```

of program text sections will be omitted for brevity and should be assumed in the program code through to the end of section 1.5.

The program text below introduces a simple macro which provides places within the definitions of each architecture for assembly language instructions (`asm`) register definitions (`rgs`) operation definitions (`ops`) and routines defined in a meta-circular manner (`exo`:)

```
    <: ‘cap,env,lang,arch, <* cpus, _ *> ~ (
        @[ ^ asm :~ $ ];
        @[ ^ rgs :~ $ ];
        @[ ^ ops :~ $ ];
        @[ ^ exo :~ >$< ];
        $ );  :>
```

The following nested pair of definitions uses a macro to transform a tabular arrangement of items into a sequence of definitions which are specialized according to the macro's expansion. This macro expands on the contents of arguments which will be supplied to parameters of the definitions instead of on the contents of a previously declared item as before.

arguments, parameters

```
[ 'ty 'lo /t/ 'co 'bo :~ (

   [ 'ar  |t| 'da :~ (<:‘lo,ar~ [<. co, _ .> : ty ~  <. da, _ .> ]; :> )];

  bo )];
```

The definitions can be used as follows to declare the integer register size and the number of integer and floating point a registers in a bank as well as the number of banks and whether or not there are register windows for each of the architectures. But first a datum type is needed:

```
‘lang,indp,mch,typ~([:([ dat ])~]; $);
```

And then the macro is used:

```
( dat )
lang,arch /t/ ( risize; ibregs; ibs; fbregs; fbs; rgws )(
x86l      |t| (   8   ;   8   ;  2 ;    8  ;  1 ;  0   );
x86m      |t| (   4   ;   8   ;  1 ;    8  ;  1 ;  0   );
x86s      |t| (   2   ;   8   ;  1 ;    8  ;  1 ;  0   );
armm      |t| (   4   ;   16  ;  1 ;   32  ;  1 ;  0   );
ppcl      |t| (   8   ;   32  ;  1 ;   32  ;  1 ;  0   );
ppcm      |t| (   4   ;   32  ;  1 ;   32  ;  1 ;  0   );
spkl      |t| (   8   ;   32  ;  1 ;   32  ;  1 ;  1   );
mmix      |t| (   8   ;  256  ;  1 ;    0  ;  0 ;  0   ));
```

The effect of the macro when used as above is to create the equivalent of 48 lines of program text like the following:

```
‘lang,arch,x86l ~ ( [ risize : datum ~  8 ];  $ );
```

The outer definition for column headings identified by the literal `/t/` has four parameters: the `type`, the `location`, the `columns`, and the `body`. The inner definition for rows of table data identified by the literal `|t|` has two: the `architecture`, and the `data`.

literals

unbound reference, lexical scope

The `ty` parameter in `/t/` is not referenced in `/t/` itself but it is refered to in the body of |`t`|, where `ty` is an unbound reference. When `/t/` itself is *referenced* and receives its arguments the parameter `ty` receives the argument `datum`. Each time |`t`| is *referenced* in the code above `ty` is bound to `datum` for those iterations of macro expansion. Expansion is necessarily delayed until arguments are received by parameters.

A new type identifies register definitions and another set of definitions with embedded macros will help with defining the registers for each architecture:

```
‘lang,indp,mch,typ~([:([reg])~]; $);

[  ’lo  /r/ ’co ’bo :~ (

  [ ’ar |i| ’da :~ (
     <:‘lo,ar~[<.co,_.>:reg~ [indx:~(<.da,_.>   ; $ ) ]]; :> )];
  [ ’ar |a| ’da :~ (
     <:‘lo,ar, <.co,_.>    ~([bank:~(<.da,_.>)]); :> )];
  [ ’ar |r| ’da :~ (
     <:‘lo,ar~[<.co,_.>:reg~([indx:~ <.da,_.>];[bank:~0]))]];:>)];

  bo )];
```

In the above set of nested definitions, the |`r`| inner definition is used for architectures that have only one bank of registers (bank 0.) An architecture where a register may have a bank other than 0 will use the |`i`| definition for the index of the registers and then the |`a`| definition for the bank, as follows:

```
   lang,arch
        /r/(  pgc;  acc;  tmp;  stk;  frm;  lnk;  ar2;  vr2 )(
  x86l  |i|(   -1;    0;    3;    4;    5;   -1;    6;    5 );
  x86l  |a|(   -1;    0;    0;    0;    0;   -1;    0;    1 );
  x86m  |r|(   -1;    0;    3;    4;    5;   -1;    6;   -1 );
  x86s  |r|(   -1;    0;    3;    4;    5;   -1;    6;   -1 );
  armm  |r|(   15;    0;    1;   13;   11;   14;    2;    4 );
  ppcl  |r|(   -1;    3;   30;   14;    1;   29;   15;    4 );
  ppcm  |r|(   -1;    3;   30;   14;    1;   29;   15;    4 );
  spkl  |r|(   -1;    8;    4;   14;   30;   15;    9;   16 );
  mmix  |r|(   -1;    0;   16;  253;  254;   -1;    1;   17 ));
```

The numbers above tabulate which register in the regular register file for each architecture is to be used for a program counter, accumulator, stack pointer, etc. In some cases a special purpose register is not exposed in the regular register file in which case a -1 is recorded in the table. For architectures with banks of

registers (e.g. the x86l) a bank value is also defined in parallel.

The effect of the macro when used as above is to create the equivalent of 72 lines of program text like:

```
‘lang,arch,x86l~([ vr2 : reg ~ ([ indx :~ 5 ]; $ )]; $ );
```

and:

```
‘lang,arch,x86l,vr2~( [ bank :~ 1 ]; $ );
```

The following macro expansion definitions create for each architecture all of the definitions for general registers of that architecture.

```
[ defregs ’a ’c : a ? nbnk ~ ( <: ‘arch,a~(
 [ r\<*0:x:{c-1}*> :reg~([indx:~  x      ];[bank:~   0     ])]); :> $ )];

[ defregs ’a ’c : a ? ybnk ~(  <: ‘arch,a~(
 [ r\<*0:x:{c-1}*> :reg~([indx:~{ x % 2 }];[bank:~{x/(c/2)}])]); :> $ )];

<: defregs <.arch,cpus,_.> <.arch,cpurc,_.>; :>
```

The above macros expand to definitions like the following:

```
‘arch,armm~( [ r0 : reg ~([ indx :~ 0 ];[ bank :~ 0 ]) ]; $ );
```

and:

```
‘arch,x86l~( [ r15 : reg ~([ indx :~ 7 ];[ bank :~ 1 ]) ]; $ );
```

In this scheme the registers of the Intel architecture are not named e.g. (r,e)ax, cx, dx, bx, sp, bp, si, and di but instead are named r0, r1, r2, r3, r4, r5, r6, and r7 respectively.

Some of the general purpose registers are dedicated to specific tasks. r0 on the Intel architecture, which is commonly known as rax or eax or ax, is used to accumulate the results of computations and has also been defined with the same indx and bank values as ’acc’. On the Sparc processor acc (the accumulator) is also known as r8.

Macro expansion uses sequences of items such as:

```
[ fruit :~ ( apple ; banana; pear; orange; grape; kiwi ) ];
[ beverage :~ ( soda; wine; distillate; juice ) ];
[ container :~ ( can; bottle; flask; carton ) ];
```

Program text for macro expansion is surrounded by `<:` and `:>` .

Expansion is driven by `<*` reference , `_ *>` where several generator references multiply, or `<.` reference , `_ .>` where several generator references advance lock-step.

```
<:  [ <* fruit, _ *> processor :~ $ ]; :>
```

A variable may be bound to the generated term for later referral.

```
<:  ‘ <* fruit, _x *> processor ~ (
[ makes x <* beverage, _ *> :~ ]; $ ); :>
```

Lock-step expansion requires source generators with an equal set of items each.

```
[ package ’a in ’b :  a type ~ a routine ];
<:  package <.  beverage, _ .> in <.  container, _ .>; :>
```

A dollar-sign wrapped in greater and less-than signs mark a content area for receiving externally generated constructs. Meta-circular systems eventually define the constructs.

```
[ external def :~ >$< ];
[ new def :~ external def, never before seen item ];
```

i syntax, continued.

1.5.2 No Operation, Return from Subroutine

Requirement — Define No Operation, Return Instructions. 04/15/2009 ✓

constants

Computer programs are fundamentally built of machine instructions. For each machine instruction one or more byte values are included in the image for the routine being constructed. One instruction (that does nothing but increment the instruction pointer) for all architectures is the nop, or no-operation instruction. A similarly simple binary value instructs the processor to return from a subroutine. Machine instructions and routines have a type, so a type for binary machine code is needed:

```
‘lang,indp,mch,typ~([:([bin])~]; $);
```

A place is made in each architecture for assembly instruction definitions:

```
<: ‘lang,arch,<. lang,indp,cpus, _ .> ~([ asm:~ $ ]); :>
```

The cap system introduces a type for instruction formats, a place for formats common to all architectures, and a place in each architecture for architecture specific format definitions:

```
‘lang,indp,mch,typ~([:([fxp])~]; $);
‘lang,indp,mch ~([ fmt:~ $ ]);
<: ‘lang,arch,<.lang,indp,cpus,_.> ~([ fmt:~(^lang,indp,mch,fmt; $)]); :>
```

One format that is the same for all architectures is that of the constant opcode:

```
‘lang,indp,mch,fmt~( [ enc c ’z :fxp~ z ]; $ );
```

The preceding encoding format simply declares that the opcode constant be placed in the machine code routine without modification. The following definitions and macros will help define opcodes that use a previously defined encoding format (such as the ’c’ format just shown.)

```
[ ’ty ’lo ’pa ’op /o/ ’co ’bo :~ (

 [ ’ar ’f1 |o| ’da :~(
   <:‘lo,ar,asm~[ op,(mknm <.co,_.> <*f1,_f*> ) :ty~(
      lo,ar,fmt,(enc f <.da,_.> \(<.pa,_.>) ); :> )];
 [ ’ar ’f1 ’f2 |o| ’da :~(
   <:‘lo,ar,asm~[ op,(mknm <.co,_.> <*f1,_f*>\<*f2,_g*> ) :ty~(
      lo,ar,fmt,(enc f\g <.da,_.> \(<.pa,_.>) ); :> )];
  bo; )];
```

The above subordinate |o| definition includes a macro which expands in the architecture for the row, introducing definitions named by the column header item 0, those definitions containing a machine instruction encoded in the format specified by the column entry item 1, with the binary value of the column entry item 0, and with the additional parameters to the instruction encoding provided by the column header item 1. The macro can be used to create the definitions of the no-operation and the return instructions as follows:

```
(bin) lang,arch () ([mknm 'op 'f :~ op ])
         /o/(   nop      ;  return    )(
x86l (c) |o|( 0X90       ; 0XC3       );
x86m (c) |o|( 0X90       ; 0XC3       );
x86s (c) |o|( 0X90       ; 0XC3       );
armm (c) |o|( 0X0000A0E1 ; 0X1eff2fe1 );
ppcl (c) |o|( 0X60000000 ; 0X4E800020 );
ppcm (c) |o|( 0X60000000 ; 0X4E800020 );
spkl (c) |o|( 0X01000000 ; 0X81C3E008 );
mmix (c) |o|( 0XFD000000 ; 0XF8000000 ));
```

The return operation above merely redirects the processor to the next instruction in the routine from which the current subroutine was called. Processors differ in how much else the instruction may do to the processor state (manipulate the stack, shift register windows, etc.) and whatever else is required for a complete calling convention (detailed for cap in section 6 of this chapter.)

The native assembly-language equivalents of the above machine code are as follows:

```
        nop     return
  x86l  nop     ret
  x86m  nop     ret
  x86s  nop     ret
  armm  nop     bx lr
  ppcl  nop     blr
  ppcm  nop     blr
  spkl  nop     jmpl %r15+8,%r0
  mmix  nop     pop 0,0
```

Not much can be done with just the two above instructions:

```
^cap,env,lang,arch,x86m,asm;
@[ waste some time :~(  nop;  nop;  nop;  nop; )];
@[ a leaf subroutine :~( waste some time; return )];
a leaf subroutine;
```

...but the above program text will produce actual executable machine code appropriate for Intel's Pentium cpu.

1.5.3 Register Integer Operations

Requirement — Define Register Integer Operations. 04/17/2009 ✓

The register integer operations such as shift, add, subtract, etc. will use different instruction formats, specialized for each architecture and for register-register-immediate (r-r-i, e.g. `r1 from r1 shl 8`) or register-register-register (r-r-r, e.g. `acc from acc sub tmp`.) Complex binary values can be constructed from simple binary values by using the 'or' binary operation to accumulate simple values that have been appropriately shifted. A couple of 'pack' definitions will help with value construction:

```
[ pack 'sz 'va 'sl 'vb :~ { sz <== (( va << sl ) | vb )} ];
[ p2  'sz 'v1 's1 'v2 's2 'vb :~ pack sz v1 s1 (pack sz v2 s2 vb ) ];
[ pf 'sz 'v1 's1 'vb :~ pack ar,fmt,sz ar,fmt,v1 ar,fmt,s1 vb  ];
```

A constant value may be required to occupy only a certain number of bits, even if it is negative (i.e. with leading ones):

```
[ chop 'sz 'ma 'vb :~ { sz <== ( ma ^| vb )} ];
```

compile time macro execution

The body of the 'pack' definition above, which includes a left shift, a binary-xor, and a fixed-size-assertion, is not passively stored but is instead immediately executed at the time the pack is referenced (as indicated by the curly-brackets) and the binary value result is made available to the referrer, rather than the sequence of instructions that comprise the mathematical operations. This feature of `i` syntax is analogous to the compile-time macro[14] facility presented by many other languages. Pack2 uses pack twice.

```
[ pr 'ar 'ra 'rb 'rd 'op :~
    p2   ar,fmt,sz1   ra,indx   ar,fmt,ra   ra,bank   ar,fmt,ba (
   p2   ar,fmt,sz1   rb,indx   ar,fmt,rb   rb,bank   ar,fmt,bb (
  p2   ar,fmt,sz1   rd,indx   ar,fmt,rd   rd,bank   ar,fmt,bd op ))];

[ pi 'ar 'ra 'ic 'rd 'op :~
      p2   ar,fmt,sz1   ra,indx   ar,fmt,ra   ra,bank   ar,fmt,ba (
     p2   ar,fmt,sz1   rd,indx   ar,fmt,rd   rd,bank   ar,fmt,bd (
    p2   ar,fmt,sz1   ic     (chop ar,fmt,sz1 ar,fmt,icm ar,fmt,ics)
        ar,fmt,cx   ar,fmt,cs   op ))];
```

[14] McIlroy, M.D., Macro Instruction Extensions of Computer Languages, Communications of the ACM 3 no. 4 (April 1960), pp. 214-220

Packrrr encodes into the provided base opcode value (op) the register index (ra, rb, rd) and bank (ba, bb, bd) for three registers. If the register bank is 0 then packing the bank makes no change to the instruction (xor with 0 is no-op) so architectures without banks can be treated as having a bank of 0 for all registers.

A set of generalized pack definitions can be specialized on the kind of operation (e.g. register-signed-carry or immediate-unsigned-notcarrying):

```
[ri:~(r;i)];[su:~(s;u)];
<: [ fx\<*ri,_e*>\<*su,_f*>:([e\f])~];
   [ pg 'v 'r 'a 'b 'd 'o : v ? e\f ~
        p\e r a b d (pf sz1 f\x f\s o)))];  :>
```

The above macro produces four pairs of definitions like the following, one each for the rs, ru, is, and iu versions of integer arithmetic operations:

```
[fxrs:([rs])~];
[ pg 'v 'r 'a 'b 'd 'o : v ? rs ~
     pr r a b d (pf sz1 sx ss o)))];
```

Another table tranforming macro is customized for sub-elements of an architecture:

```
[ 'ty 'lo 'su 'pr /s/ 'co 'bo :~ (
 [ 'ar |s| 'da :~ (<:‘lo,ar,su~ [<. co, _ .> : ty ~  <. da, _ .> ]; :> )];
 pr;  bo )];
```

A table contains the offsets for shifting register and bank values as well as the size of the instructions and the value, offset, and size mask for immediate values.

```
(bin) lang,arch (fmt) (^indp,bo)
     /s/ (  sz1  ;ra;ba;rb;bb;rd;bd;sx;ss;cx;cs;ux;us;nx;ns;ics;icm   )(
x86l |s| ( be,i24;0 ;8 ;3 ;10;0 ; 0;  ;  ;  ;  ;  ;  ;  ;  ;   ;      );
x86m |s| ( be,i16;0 ;0 ;3 ;0 ;0 ; 0;  ;  ;  ;  ;  ;  ;  ;  ;   ;      );
x86s |s| ( be,i16;0 ;0 ;3 ;0 ;  ; 0;  ;  ;  ;  ;  ;  ;  ;  ;   ;      );
armm |s| ( le,i32;4 ;0 ;8 ;0 ;  ; 0;  ;  ;  ;  ;  ;  ;  ;  ;   ;      );
ppcl |s| ( be,i32;5 ;0 ;0 ;0 ;22; 0;  ;  ; 0; 0;  ;  ;  ;  ; 0 ;0XFFFF);
ppcm |s| ( be,i32;17;0 ;12;0 ;22; 0;  ;  ; 0; 0;  ;  ;  ;  ; 0 ;0XFFFF);
spkl |s| ( be,i32;25;0 ;0 ;0 ;25; 0;  ;  ; 1;13;  ;  ;  ;  ; 0 ;0X1FFF);
mmix |s| ( be,i32;8 ;0 ;0 ;0 ;16; 0; 0; 0; 1;24; 2;24; 0; 0; 0 ;0XFF  ));
```

The pack definition may be used in instruction format encoding definitions as follows for register-register-register operations:

```
‘lang,indp,mch,typ~([synth:([synthetic])~]; $);
<:        ‘lang,arch,<*cpus,_x*>,fmt~(
 [  enc <*ri,_e>\<*su,_f> ’z ’a ’b ’d :z ? cell:fxp~
     pg fx\e\f x a b d z ];
 [  enc e\f ’z ’a ’b ’d :z ? synthetic:fxp~  ]; $ ); :>
```

An add, multiply, subtract, or divide instruction may be r-r-r or r-r-i, may be signed or unsigned, and may carry or not carry overflow from a previous instruction. The following table provides base op-code values and drives the definition of assembly language operations e.g. `acc from tmp addis 254`:

```
(bin) lang,arch (’a ’b ’d) ([mknm ’op ’f :~ ’d from ’a op\f ’b])
                /o/(    add    ;   mul     ;    sub    ;    div    )(
x86l (r;i)(s;u) |o|(  0X4801C0 ;           ;  0X4809C0 ;           );
x86m (r;i)(s;u) |o|(  0X01C0   ;           ;  0X09C0   ;           );
x86s (r;i)(s;u) |o|(  0X01C0   ;           ;  0X09C0   ;           );
armm (r;i)(s;u) |o|(  0X80e0   ;           ;  0X40e0   ;           );
ppcl ( r )(s;u) |o|( 0X7C000014; 0X7C0001E3; 0X7C000050; 0X7C0003D3);
ppcl ( i )(s;u) |o|( 0X38000000; 0X1C000000; 0X20000000;   synth   );
ppcm ( r )(s;u) |o|( 0X7C000014; 0X7C0001E3; 0X7C000030; 0X7C0003D7);
ppcm ( i )(s;u) |o|( 0X30000000; 0X1C000000; 0X20000000;   synth   );
spkl (r;i)(s;u) |o|( 0X80800000; 0X80480000; 0X80A00000; 0X81680000);
mmix (r;i)(s;u) |o|( 0X22000000; 0X1A000000; 0X26000000; 0X1E000000));
```

Addition and Subtraction of signed values are carrying or without carrying overflows or underflows of the machine word size from a previous operation. Addition and subtraction will set or clear the carrying state, usually implemented as a flag in a status register. And again for five binary logic instructions:

The above macros expand to definitions like the following:

```
‘arch,mmix,asm~( [ ’d from ’a addru ’b : bin ~(enc ru 0XC8000000 a b d) ]; $ );

‘arch,mmix,fmt~( [ enc ru z a b d :z ? cell:fxp~ pg fxru mmix a b d z ]; $ );
```

So the mmix-specific program code `acc from ar2 addru tmp;` results in the machine code value `0XC80000000`.

1.5.4 Register Boolean Operations

Requirement — Define Register Boolean Operations. 04/17/2009 ✓

The register boolean operations will reuse some of the integer operation definitions, and introduce some more:

```
(bin) lang,arch ('a 'b 'd) ([mknm 'op 'f :~ 'd from 'a op\f 'b])
           /o/(    and    ;  xor     ; orr      )(
x86l (r;i) |o|(0X4821C0  ;0X4831C0  ;0X4889C0  );
x86m (r;i) |o|(0X21C0    ;0X31C0    ;0X89C0    );
x86s (r;i) |o|(0X21C0    ;0X31C0    ;0X89C0    );
armm (r;i) |o|(0X000000e0;0X00000020;0X000080e0);
ppcl ( r ) |o|(0X7C000038;0X7c000278;0X7c000378);
ppcl ( i ) |o|(0X70000000;0X68000000;0X60000000);
ppcm ( r ) |o|(0X7C000038;0X7c000278;0X7c000378);
ppcm ( i ) |o|(0X70000000;0X68000000;0X60000000);
spkl (r;i) |o|(0X80080000;0X80180000;0X80100000);
mmix (r;i) |o|(0XC8000000;0XC6000000;0XC0000000));
```

```
(bin) lang,arch ('a 'b 'd) ([mknm 'op 'f :~ 'd from 'a op\f 'b])
           /o/(  shl      ;  shr     ;   cmp    )(
x86l (r;i) |o|(           ;          ; 0X483BC0 );
x86m (r;i) |o|(           ;          ; 0X3BC0   );
x86s (r;i) |o|(           ;          ; 0X3BC0   );
armm (r;i) |o|(           ;          ;          );
ppcl ( r ) |o|(           ;          ;0X7C000040);
ppcl ( i ) |o|(           ;          ;0X28000000);
ppcm ( r ) |o|(           ;          ;0X7C000040);
ppcm ( i ) |o|(           ;          ;0X28000000);
spkl (r;i) |o|(0X81281000;0X81301000;     0    );
mmix (r;i) |o|(0X3A000000;0X3E000000;0X32000000));
```

The following demonstrates native assembly-language equivalents of shifting left a register by a constant value, and xor-ing a register with itself:

```
          tmp from tmp shli 8;           tmp from tmp xorr tmp;

   x86l - 48 c1 e3 08  shl rbx, 8        48 33 db      xor rbx,rbx
   x86m - 66 c1 e3 08  shl ebx, 8        33 db         xor ebx,ebx
   x86s - c1 e3 08     shl bx,  8        33 db         xor bx,bx
   armm - 01 14 a0 01  moveq r1,r1,lsl#8 00 10 a0 e3   mov r1, #0
   ppcl - 7b de 45 e4  sldi r30,r30,8    3b c0 00 00   li r30, 0
   ppcm - 57 de 40 2e  slwi r30,r30,8    3b c0 00 00   li r30, 0
   spkl - 89 29 20 08  sll %g4,8,%g4     88 10 20 00   clr %g4
   mmix - 33 10 10 08  SLU $16,$16,8     C6 10 10 10   XOR $16,$16,$16
```

1.5.5 Load Immediate to Register

Requirement — Load Immediate to Register. 04/17/2009 ✓

immediate values

A routine of machine code instructions may require values up to the size of a machine register to be immediately loaded into registers from the instruction stream itself. Some of the architectures require several instructions to perform this task as they lack a 'load immediate register-sized value' instruction. A general routine to load a register-sized value can be synthesized from an instruction that clears a register followed by a sequence of 'orri' and 'shli' instructions.

```
(bin) lang,arch (cri) (b; c)
     /o/(  geti ‘’b ‘’c )(
x86l |o|(   0X80cb      );
x86m |o|(   0X80cb      );
x86s |o|(   0X80cb      );
armm |o|(   0xe3811c    );
ppcl |o|(   0X63DE00    );
ppcm |o|(   0X63DE00    );
spkl |o|(   0X881120    );
mmix |o|(   0X211010    ));
```

The native assembly-language equivalents of the above machine code are as follows:

```
         geti tmp b8 0xFF
x86l   or bl, 0xFF
x86m   or bl, 0xFF
x86s   or bl, 0xFF
armm   orr r1,r1, 0xFF
ppcl   ori r30,r30, 0xFF
ppcm   ori r30,r30, 0xFF
spkl   or %g4, 0xFF, %g4
mmix  ADD $16,$16, 0xFF
```

With the clear, byte-or-immediate, and shift instructions on the temporary register just defined, the temporary register can now be loaded with any value up to the capacity of the register. Since a sequence of instructions (a routine) will be used to perform such a multi-byte load two more macros will create synthetic instructions for loading two-, four-, and eight-byte values into the temporary register of each architecture, but first some definitions to drive the macros:

```
‘arch,indp,mch~([ bsq  :~  ( b8; b16; b32 )];
                [ bszh  :~ (  h8; h16; h32 )];
                [ bszl  :~ (  l8; l16; l32 )];
                [ bssq :~ ( b16; b32; b64 )];
                [ bst :~ ( b8; b16; b32; b64 )]; $ );
```

the geti b8 instruction was created previously. The following macro creates orti instructions for sizes b16, b32, and b64 by concatenating 'geti b8' and shift instructions.

```
<: ‘lang,arch, <*arch,cpus,_*> ,asm~(
   [ geti <. indp,mch,bssq, _ .> 'a :bin~(
     geti <. indp,mch,bsq, _ .> a,<. indp,mch,bszh, _ .> ;
     geti <. indp,mch,bsq, _ .> a,<. indp,mch,bszl, _ .> )]; $ ) :>
```

Loading a value using the 'or' operation depends on the register being cleared first. The following macro creates new synthetic instructions that first clear the register and then get the immediate value:

```
<: ‘lang,arch, <*arch,cpus,_*> ,asm~(
   [ ldti <. indp,mch,bst, _ .> 'a :bin~(
     clrt; geti <. indp,mch,bst, _ .> a  )]; $ ) :>
```

The ldti synthetic assembly language instruction might be used as follows:

```
ldti 0X11223344;
```

and would, when used to create armm or x86m machine code, be implemented as the byte values and equivalent native assembly language as follows:

```
00 10 a0 e3  mov   r1, #0         db 33        xor ebx,ebx
11 1c 81 e3  orr   r1,r1, 0x11    80 cb 11     or  bl, 0x11
01 14 a0 01  moveq r1,r1,lsl#8    66 c1 e3 08  shl ebx, 8
22 1c 81 e3  orr   r1,r1, 0x22    80 cb 22     or  bl, 0x22
01 14 a0 01  moveq r1,r1,lsl#8    66 c1 e3 08  shl ebx, 8
33 1c 81 e3  orr   r1,r1, 0x33    80 cb 33     or  bl, 0x33
01 14 a0 01  moveq r1,r1,lsl#8    66 c1 e3 08  shl ebx, 8
44 1c 81 e3  orr   r1,r1, 0x44    80 cb 44     or  bl, 0x44
01 14 a0 01  moveq r1,r1,lsl#8    66 c1 e3 08  shl ebx, 8
```

There are more concise ways to load a constant value from the instruction stream into a register for these architectures but this method is general across all architectures and optimization may be later applied.

1.5.6 Jumps and Calls to absolute addresses

Requirement — Define Jump and Call Instructions. 04/20/2009 ✓

The above `no operation` and `return from subroutine` definitions have values that are the same regardless of how or where they are used. For definitions which have binary values that depend on the context of their use, the system requires a way to identify what the definition depends on. In `i` (and many other programming languages) the parameters to a definition serve this function.

For example, in order to create a a jump to an absolute location in memory (as shown below) the definition needs to have passed in to it as a parameter the location in memory that is the destination of the jump.

```
[ 'ty 'lo 'ls /o/ 'co 'bo :~ (

  [ 'ar |o| 'da :~ (
     <:‘lo,ar,ls ~ ([<. co, _ .> : <. ty, _ .> ~  <. da, _ .> ]; $ ); :> )];

  bo )];
```

```
        ((   bin                  );(   bin       )) lang,arch
(asm)/o/(  jabt                    ;  cabt         )(
x86l |o|(( 0X48FFE3               );( 0X48FFE3    ));
x86m |o|(( 0XFFE3                 );( 0XFFE3      ));
x86s |o|(( 0XFFE3                 );( 0XFFE3      ));
armm |o|(( 0xe1a0f001             );( 0x0fe0e1a0; 0xe1a0f001 ));
ppcl |o|(( 0x7fc803a6; 0x4e800020 );( 0x7fa802a6; 0x7fc803a6; 0x4e800020 ));
ppcm |o|(( 0x7fc803a6; 0x4e800020 );( 0x7fa802a6; 0x7fc803a6; 0x4e800020 ));
spkl |o|(( 0X89C02000             );( 0X89C3E000  ));
mmix |o|(( 0X9F101000             );( 0XBF001000  )));
```

The native assembly-language equivalents of the above machine code are as follows:

```
      jmp abs tmp   call abs tmp
x86l   jmp *%rbx     call *%rbx
x86m   jmp *%ebx     call *%ebx
x86s   jmp *%bx      call *%bx
armm   mov pc, r1    mov lr, pc
                     mov pc, r1
ppcl   mtlr r1       mflr r29
       blr           mtlr r30
                     blr
ppcm   mtlr r1       mflr r29
       blr           mtlr r30
                     blr
spkl   jmpl %g4,%r0  jmpl %g4,%r15
mmix   GO $16,$16,0  PUSHGO $0,$16,0
```

Combining the load immediate and jump (or call) absolute via temp register instructions, we can fabricate a jump or call to any memory location:

```
<: ‘lang,arch, <.arch,cpus,_.> ,asm~(
 [ jmpa  ’a :bin~
  ( ldti <.arch,cpul,_.> ({ loc of a <.arch,cpuj,_.> }) ; jabt )];
 [ calla ’a :bin~
  ( ldti <.arch,cpul,_.> ({ loc of a <.arch,cpuj,_.> }) ; cabt )]; $ ) :>
```

parameter type functions

When definitions have parameters, type functions can be applied to the parameters. When parameters have type functions, the type functions serve as constraints which limit the applicability of that definition when it is referenced. In the case of the definitions above, the definitions are limited to apply only when the parameter refers to a value of four bytes (for the armm) or two to eight bytes (for the x86 family.)

A subroutine call is similar to a jump except that the location of execution previous to the jump is saved so that computation may continue from that point once the subroutine is done.

The above instructions allow creating loops and calling leaf subroutines as follows:

```
jmpa ( main routine );
[ sub1 ];
a leaf subroutine;
[ sub2 ];
a leaf subroutine;
[ main routine ];
calla sub1;
calla sub2;
jmpa ( main routine);
```

The Intel assembly for an absolute call is the same as for a jump, with call value replaced with jmp. The call instruction saves the return address to the stack where it will be found and used by the return from subroutine instruction. The Arm, on the other hand, uses a link register instead of the stack for subroutine return so the PC is saved to the link register before the absolute jump to the subroutine is performed, as translated below:

Type labels may be introduced and referenced between the colon and tilde sign. Type labels by default have the same scope as the enclosing definition.

```
[ apple :  ([ fruit ]) ~ ];
[ pear :  fruit ~ ];
[ beef :  ([ meat ]) ~ ];
[ pork :  meat ~ ];
```

Single quote marks denote the parameters in definition names. A type function returning true or false in the type section of a definition limits the applicability of a definition to when the function returns true.

```
[ eats 'a :  a ?  fruit ~ [ vegetarian ] ];
[ eats 'a :  a ?  meat ~ [ carnivore ] ];
```

i syntax, continued.

1.5.7 Relative Jump, Relative Subroutine Call

Requirement — Define Relative Jump and Call Instructions. 04/21/2009 ✓

macro computation

For a relative jump to another binary code location, the definition must determine the number of in bytes between the location of the branch instruction and the location being branched to. The parameter is required to be a reference to binary code. A macro computation provides the offset between the location in the image of the referenced routine and of the location in the image of the instance of the branch to be constructed.

A subroutine call also uses relative addressing. When the subroutine is called the location to return to is stored. The return instruction(s) previously defined merely instruct the CPU to resume processing at that saved location.

```
  [ mmixjop  'o : o positive ~ 0xf0 ];
  [ mmixjop  'o : o negative ~ 0xf1 ];
  [ mmixpjop 'o : o positive ~ 0xf2 ];
  [ mmixpjop 'o : o negative ~ 0xf3 ];
  [ spkljop  'o : o positive ~ 0X1080 ];
  [ spkljop  'o : o negative ~ 0X10BF ];
  [ spklpjop 'o : o positive ~ 0x4000 ];
  [ spklpjop 'o : o negative ~ 0x7FFF ];
        ((   bin               );(   bin       )) lang,arch
(asm)/o/(  jrels 'o             ;  crels 'o        )(
x86l |o|(( 0xe9; o             );( 0xe8; o         ));
x86m |o|(( 0xe9; o             );( 0xe8; o         ));
x86s |o|(( 0xe9; o             );( 0xe8; o         ));
armm |o|(( o; 0xea             );( o; 0xeb         ));
ppcl |o|(( 0x48;  o            );( 0x48; { o && 1 }));
ppcm |o|(( 0x48;  o            );( 0x48; { o && 1 }));
spkl |o|(((spkljop o ); o; nop );((spklpjop o ); o; nop )));
mmix |o|(((mmixjop o ); o      );((mmixpjop o ); o )));
```

The native assembly-language equivalents of the above machine code are as follows:

```
        jrels o          crels o
x86l    jmp < o >        call < o >
x86m    jmp < o >        call < o >
x86s    jmp < o >        call < o >
armm    b < o >          bl < o >
ppcl    b < o >          bl < o >
ppcm    b < o >          bl < o >
spkl    ba < o >         call < o >
        nop              nop
mmix    JMP < o >        PUSHJ < o >
```

A macro will create definitions which compute the offset:

```
<: ‘lang,arch, <.arch,cpus,_.> ,asm~(
   [ jmpr  ’a :bin~([l]; jrels ({ offset a to l <.arch,cpuj,_.> }) )];
   [ callr ’a :bin~([l]; crels ({ offset a to l <.arch,cpuj,_.> }) )]; $ ) :>
```

Relative jumps are limited to offsets less (sometimes far less) than the addressable address space of the architecture. The following example code may look like the previous one but because the jumps and calls are relative the binary routine produced by the code below can be relocated without adjusting the destinations of the calls and jumps:

```
jmpr ( main routine );
[ sub1 ];
a leaf subroutine;
[ sub2 ];
a leaf subroutine;
[ main routine ];
callr sub1;
callr sub2;
jmpr ( main routine);
```

Up to this point in the description of `cap` everything is defined before it is referred to. Now, however, the definitions are using functions that have not been defined previously in the source text (e.g. ’location of a’ in the above code.) This will be resolved by borrowing those routines from an already existing `cap` system.[15] The procedures used but not yet defined will be defined later in this text. A system that is implemented in terms of its own functionality is meta-circular.

meta-circular

[15] Ken Thompson, Reflections on trusting trust, Communications of the ACM, 27(8):761-763, August 1984

`'r ? 't` fails if r is not type t
`'a positive` fails if the value of a is not positive
`'a negative` fails if the value of a is not negative
`'a == 'b` fails if the value of a is not the same value as b
`'a land 'b` fails if either a or b fail
`'a lor 'b` fails if both a and b fail
`offset 'a to 'l 's` presents the difference between the locations of a and l in a value of size s
`'a - 'b` presents a - b
`'a + 'b` presents a + b
`'a / 'b` presents a / b
`'a percent 'b` presents a mod b
`'a band 'b` presents a bit-wise-and b
`'a bor 'b` presents a bit-wise-or b
`'a << 'b` presents a shift by b
`i64le <= 'a` presents the 64-bit value of a
`i32le <= 'a` presents the 32-bit value of a
`i24le <= 'a` presents the 24-bit value of a
`i16le <= 'a` presents the 16-bit value of a
`i8 <= 'a` presents the 8-bit value of a

Functions used but not yet defined.

Curly-brackets enclose items which are to be instantiated in a separate image location and then to have execution passed to them so that the computation described within the curly brackets can happen at the time of construction (instantiation) of the enclosing definition.

```
[ general 'a :  a ?  foo ~ { munge a }; do b ];
[ general 'a :  a ?  bar ~ { chomp a }; do b ];
```

More explanation.

```
[ general 'a :  a ?  foo ~ { munge a }; do b ];
```

i syntax, continued.

1.5.8 Register Move

Requirement — Define Register Move Instructions. 04/23/2009 ✓

Binary code for moving values between registers in the x86l architecture is as simple to construct as a jump definition, but providing a separate definition for each combination of source and destination registers would be tedious. A compile time calculation based on the register number and bank number will

require much less coding.

Register index and bank values are often packed in with a constant to create machine codes for operations on registers. Two macros will assist with the packing:

```
[ p2i a sa b in sz      :~{sz <== (b+(a,indx << sa))}];
[ p3i a sa b sb c in sz :~{sz <== (c+((a,indx << sa)+(b,indx << sb)))}];
[ p3b a sa b sb c in sz :~{sz <== (c+((a,bank << sa)+(b,bank << sb)))}];
```

With definitions for general purpose registers and macros to pack values operations can be defined, including loading to a register via another register:

```
( (( a ? reg ) && ( b ? reg)) ; bin )
lang,arch/t/(               'a to 'b                        )(
x86l,asm |t|((          p3b b 2 a 0 0x48 in i8;
                  0x89; p3i b 3 a 0 0xc0 in i8              ));
x86m,asm |t|((    0x89; p3i b 3 a 0 0xc0 in i8              ));
x86s,asm |t|((    0x89; p3i b 3 a 0 0xc0 in i8              ));
armm,asm |t|(( b,indx ; p2i a 4 0x00 in i8; 0xe1a0;         ));
ppcl,asm |t|((          p3i a 5 b 0 0x6000 in i16be ; 0x0000 ));
ppcm,asm |t|((          p3i a 5 b 0 0x6000 in i16be ; 0x0000 ));
spkl,asm |t|((          p3i a 25 b 15 0x8010200 in i32be     ));
mmix,asm |t|((    0xC1; b,indx; a,indx; 0x00                 )));
```

The native assembly-language equivalents of the above machine code are as follows:

```
       a to b
x86l   movq %< b >, %< a >
x86m   movd %< b >, %< a >
x86s   mov  %< b >, %< a >
armm   mov  < b >, < a >
ppcl   ori  < b >, < a >, 0
ppcm   ori  < b >, < a >, 0
spkl   or %< a >, 0, %< b >
mmix   OR $< b >,$< a >,0
```

The above instructions can be used in the following manner, but only for the registers that are defined for the architecture the routine is being crafted for. An x86 processor must not be asked to move data to or from r31, for example.

```
r1 to r3;
acc to tmp;
tmp to r5;
```

1.5.9 Register Load / Store

Requirement — Define Register To Memory Instructions. 05/05/2009 ✓

The load and store instructions for each architecture share some common characteristics. A couple of tables collect the particulars of how each architecture encodes its instructions, a 'build-load-store' definition describes a way to construct a load or store instruction from the table and then a macro drives the creation of the instructions for each architecture.

The first table provides the base binary value of the machine instruction to load or store an 8, 16, 32, or 64-bit value for each architecture.

```
<: ‘lang,arch,<. lang,indp,cpus, _ .> ~([ ldst:~ $ ]); :>

        ( s==b8  ; s==b8  ; s==b16;  s==b16 ; s==b32 ; s==b32 ; s==b64 ; s==b64 )
lang,arch (ldst)
     /o/( st ’s  ; ld ’s  ; st ’s  ; ld ’s  ; st ’s  ; ld ’s  ; st ’s  ; ld ’s  )(
x86l |o|(0X904088;0X90408A;0X664189;0X66418B;0X674889;0X67488B;0X904889;0X90488B);
x86m |o|( 0X9088 ; 0X908A ; 0X6689 ; 0X668B ; 0X6789 ; 0X678B ;  ()    ;   ()   );
x86s |o|( 0X90   ; 0X90   ; 0X89   ; 0X8B   ;   ()   ;   ()   ;  ()    ;   ()   );
armm |o|(0xe5c000;0xe5d000;0xe1c000;0xe1d000;0xe50000;0xe51000;  ()    ;   ()   );
ppcl |o|( 0XA000 ; 0X8800 ; 0XE800 ; 0X8000 ; 0XB000 ; 0X9800 ; 0XF800 ; 0X9000 );
ppcm |o|( 0XA000 ; 0X8800 ; 0XE800 ; 0X8000 ; 0XB000 ; 0X9800 ;  ()    ;   ()   );
spkl |o|(0XC02120;0XC00120;0XC03020;0XC01020;0XC02020;0XC00020;0XC03820;0XC01820);
mmix |o|(0XA30000;0X830000;0XA70000;0X870000;0XAB0000;0X8B0000;0XAF0000;0X8F0000));
```

The second table contains the amounts by which to shift the index and bank values of registers for their placement in the machine instruction for their role as the source/destination register or the register holding the memory location:

```
        (dat;dat;dat;dat;dat;dat ;dat;dat;dat; dat ; dat ) lang,arch
(ldst)/o/(dp; ar; br; ab; bb;cpad; sp; sn;ns ;lopsz;ofsz )(
x86l  |o|( 1;  0;  3;  8; 10;0x40;  0;  0; 0 ;i24le; i8  );
x86m  |o|( 1;  0;  3;  0;  0;0x40;  0;  0; 0 ;i16le; i8  );
x86s  |o|( 1;  0;  3;  0;  0;0x40;  0;  0; 0 ; i8  ; i8  );
armm  |o|( 0;  4;  8;  0;  0; () ;  1;  0;15 ;i24le; i8  );
ppcl  |o|( 1;  5;  0;  0;  0; () ;  0;  0; 0 ;i16be;i16be);
ppcm  |o|( 1;  5;  0;  0;  0; () ;  0;  0; 0 ;i16be;i16be);
spkl  |o|( 1; 17;  6;  0;  0; () ;  0;  0; 0 ;i24be;i24be);
mmix  |o|( 1;  8;  0;  0;  0; () ;  0;  0; 0 ;i24le; i8  ));
```

The columns in the above table have the following meanings:

```
dp - data position
ar - 'a' register index shift by    br - 'b' register index shift by
ab - 'a' register bank shift by     bb - 'b' register bank shift by
cr - 'c' register index shift by    lopsz  - load/store operand size
```

A load or store instruction for an architecture is made by packing a sequence of binary values with each of the above characteristics, each one appropriately coded and shifted. Packing items can be done with the following definition, which is also aliased for easier expansion:

```
^([ buildldst 'cpu 'lsz 'op 'a via 'b offset 'c :~ $ ])~bl;
```

A definition for pack is made privately within buildldst. The pack definition shifts left the value it receives and adds that to whatever it gets in its third parameter. All values are assumed to fit in a 'lopsz' value as defined by the 'cpu' architecture received from the containing buldldst.

```
‘bl~( @[ negflag 'c : positive c ~ cpu,ldst,sp ];
      @[ negflag 'c : negative c ~ cpu,ldst,sn ];
      @[ pack 'va 'sl 'vb :~ { cpu,ldst,lopsz <== (( va << sl ) + vb )} ]; $ );
```

That definition is used to pack the opcode received (which is not shifted, and which specifies already whether the operation is a load or a store and whether the value moved is 8, 16, 32, or 64 bits in size) and the next thing,

```
‘bl~(  pack op 0 ($) );
```

which is the index of the register to receive or supply the value. After that is packed the bank for that register.

```
‘bl~(  pack a,indx cpu,ldst,ar ($) );
‘bl~(  pack a,bank cpu,ldst,ab ($) );
```

Same for the register that contains the memory location:

```
‘bl~(  pack b,indx cpu,ldst,br ($) );
‘bl~(  pack b,bank cpu,ldst,bb ($) );
```

The negative or positive offset flag is similarly packed depending on whether the offset is positive or negative:

```
‘bl~(  pack (negflag c) cpu,ldst,ns ($) );
```

The first four of the following definitions allow for a definition to tailor its results on whether or not the offset constant comes at the begin or the end of the instruction, and whether or not the absolute value of the offset should be stored. The last two drive the macro to create load and store instructions.

```
[ pos ’dp ’c ’b ’p : dp == 0 ~ ( p; c; b )];
[ pos ’dp ’c ’b ’p : dp == 1 ~ ( b; p; c )];
[ absc ’az ’dp ’c : dp == 0 ~ { az <== c } ];
[ absc ’az ’dp ’c : dp == 1 ~ { az <== ( abs c )}];
[ altlsn :~( load ; store )];
[ altlsd :~( to ; from )];
[ altls :~( ld ; st )];
```

A macro will create load/store instructions for each architecture using the pack definition.

```
<: ‘lang,arch, <*arch,cpus,_a*> ,asm~(
[ <. altlsn,_ .> ’lsz <<: altlsd,_ :>> ’r via ’m offset ’c :~
  pos ‘arch,a,ldst,dp ( absc  ‘arch,a,ldst,ofsz ‘arch,a,ldst,sp c )
  ( buildldst a lsz ‘arch,a,ldst,(<<:altls,_:>> lsz ) r via m offset c )
    ‘arch,a,ldst,cpad ]; $) :>
```

The above instructions can be used in the following manner, but only for the registers that are defined for the architecture the routine is being crafted for. An x86 processor must not be asked to load data to r31, for example.

```
load b32 to r3 via r5 offset 8;
store b64 from acc via tmp offset -64;
load b8 to acc via frm offset 0;
```

1.5.10 Integer Register Operations

Requirement — Define Integer Register Operations. partial

There are a common set of intger register operations that most architectures support. As with register loads and stores, these operations are composed in a regular way. Some tables will collate specific encodings, construction definitions will facilitate composition, and a macro will create the assembly operation definitions.

The first table provides the base binary value of the machine instruction for a particular operation.

```
    ‘lang,indp,mch,typ~([:([op])~]; $);

        ( op; op; op; op; op )  (lang,arch)
(ops)/o/(   add    ;   adc    ;   sub    ;    sbc   ;   cmp    )(
x86l |o|( 0X4801C0 ; 0X4811C0 ; 0X4809C0 ; 0X4819C0 ; 0X483BC0 );
x86m |o|( 0X01C0   ; 0X11C0   ; 0X09C0   ; 0X19C0   ; 0X3BC0   );
x86s |o|( 0X01C0   ; 0X11C0   ; 0X09C0   ; 0X19C0   ; 0X3BC0   );
armm |o|( 0xe080   ; 0x       ; 0xe040   ; 0xe0c0   ;          );
ppcl |o|( 0x       ;0x        ;          ;          ;0x        );
ppcm |o|( 0x       ;0x        ;0x        ;0x        ;0x        );
spkl |o|( 0x       ;0x        ;0x        ;0x        ;0x        );
mmix |o|(0X20000000;    ()    ;0X24000000;    ()    ;          ));

        ( op; op; op; op; op )  (lang,arch)
(ops)/o/(    and    ;    xor   ; orr      ;    shl   ;    shr   )(
x86l |o|( 0X4821C0  ;0X4831C0  ;0X4889C0  ;0x        ;0x        );
x86m |o|( 0X21C0    ;0X31C0    ;0X89C0    ;0x        ;0x        );
x86s |o|( 0X21C0    ;0X31C0    ;0X89C0    ;0x        ;0x        );
armm |o|( 0xe000    ;0x2000    ;0xe080    ;0x        ;0x        );
ppcl |o|( 0x        ;0x        ;0x        ;0x        ;0x        );
ppcm |o|( 0x        ;0x        ;0x        ;0x        ;0x        );
spkl |o|( 0x        ;0x        ;0x        ;0x        ;0x        );
mmix |o|( 0XC8000000;0XC6000000;0xC0000000;0x        ;0X24000000));
```

The second table contains the amounts by which to shift the index and bank values of the two source registers and the destination register. Some architectures (e.g. the x86) require that the second source register be the same as the destination register.

```
          (dat;dat;dat;dat;dat;dat ;dat;dat;dat; dat ; dat ) lang,arch
   (iop) /o/( ar; br; cr; ab; bb; cb; h3;   ;   ;iopsz;     )(
   x86l  |o|(  0;  3;  0;  8; 10;  0;  0;   ;   ;i24be;     );
   x86m  |o|(  0;  3;  0;  0;  0;  0;  0;   ;   ;i16be;     );
   x86s  |o|(  0;  3;  0;  0;  0;  0;  0;   ;   ;i16be;     );
   armm  |o|(   ;   ;   ;  0;  0;  0;  1;   ;   ;     ;     );
   ppcl  |o|(   ;   ;   ;  0;  0;  0;  1;   ;   ;     ;     );
   ppcm  |o|(   ;   ;   ;  0;  0;  0;  1;   ;   ;     ;     );
   spkl  |o|(   ;   ;   ;  0;  0;  0;  1;   ;   ;     ;     );
   mmix  |o|( 16;  8;  0;  0;  0;  0;  1;   ;   ;i32be;     ));
```

An integer operation for an architecture is made by packing a sequence of binary values with each of the above characteristics, each one appropriately coded and shifted. Packing items can be done with the following definition, which is also aliased for easier expansion:

```
^([ buildintop 'cpu 'lsz 'op 'a via 'b offset 'c :~ $ ])~bi;
```

A definition for pack is made privately within buildintop. The pack definition shifts left the value it receives and adds that to whatever it gets in its third parameter. All values are assumed to fit in a 'lopsz' value as defined by the 'cpu' architecture received from the containing buldldst.

```
‘bi~( @[ pack 'va 'sl 'vb :~ { cpu,ldst,lopsz <== (( va << sl ) + vb )} ]; $ );
```

That definition is used to pack the opcode received (which is not shifted, and which specifies already whether the operation is a load or a store and whether the value moved is 8, 16, 32, or 64 bits in size) and the next thing,

```
‘bi~(  pack op 0 ($) );
```

which is the index of the register to receive or supply the value. After that is packed the bank for that register.

```
‘bi~(  pack a,indx cpu,ldst,ar ($) );
‘bi~(  pack a,bank cpu,ldst,ab ($) );
‘bl~(  pack b,indx cpu,ldst,br ($) );
‘bl~(  pack b,bank cpu,ldst,bb ($) );
‘bl~(  pack b,indx cpu,ldst,br ($) );
‘bl~(  pack b,bank cpu,ldst,bb ($) );
```

With the above table the instructions can be defined:

```
lang,arch/t/(  'a <-- 'a  'o 'b                                    )(
armm,asm |t|((b, {i8 <== ( o,ord * 16 )};
              {i8 <== ( a,ord + o,b2 )}; o,b1                       ));
```

The above instructions can be used in the following manner, but only for the registers that are defined for the architecture the routine is being crafted for. An x86 processor must not be asked to xor r31 and r24, for example.

```
r7  and r9  to r5;
acc xor tmp to acc;
r1  cmp 0   to r2;
acc sub 4   to acc;
r31 xor r31 to r31;
```

1.5.11 Stack Oprerations

Requirement — Define Stack Operation Instructions. 01/30/2009 ✓

And the stack is generally considered a good idea:

```
    ‘lang,indp,mch,typ~([:([sasmop])~]; $);

  ( sasmop )
  lang,arch    /t/(  pop  ;  push )(
  x86l,ops     |t|( 0x58  ; 0x50  );
  x86m,ops     |t|( 0x58  ; 0x50  );
  x86s,ops     |t|( 0x58  ; 0x50  );
  armm,ops     |t|( 0xee8bd; 0xe92d);
  ppcl,ops     |t|( 0x??  ; 0x??  );
  ppcm,ops     |t|( 0x??  ; 0x??  );
  spkl,ops     |t|( 0x??  ; 0x??  );
  mmix,ops     |t|( 0x????; 0x????));

  ((( a ? reg )&&( o ? sasmop )) ; bin )
  lang,arch/t/(  ’o register ’a                                    )(
  x86l,asm |t|(( {i8 <== ( 0x40 +  a,bank ) };{i8 <== ( o +  a,ord ) }));
  x86m,asm |t|(( {i8 <== ( o +  a,ord ) }                          ));
  x86s,asm |t|(( {i8 <== ( o +  a,ord ) }                          ));
  armm,asm |t|(( {i16le <== ( 0x01 << a,ord ); o  }                 ));
  ppcl,asm |t|(( {i8 <== ( 0x?? +  a,bank ) };{i8 <== ( o +  a,ord ) }));
  ppcm,asm |t|(( {i8 <== ( ??         ) }                          ));
  spkl,asm |t|(( {i8 <== ( ??         ) }                          ));
  mmix,asm |t|(( {i16le <== ( 0x?? << a,ord ); o  }                 )));
```

1.5.12 Load Register with Constant

Requirement — Define Load Constant Instructions. unmet

The previous two assembly language definitions redirect the flow of execution for the binary code they are instantiated within. The next load constant values into registers:

```
‘cap,env,lang,arch,gen ~  (

   instruction ( load ’a with ’b )
    with (( a ? reg )&&( b # 8 )) over (
   for x86l is ( {i8 <== ( 0x48 +  a,bank ) };
                 {i8 <== ( 0xB8 +  a,ord ) }; b  ));
 $ );
```

Of the defined architectures so far, only the x86l has 64-bit registers to

receive a 64-bit constant.

```
‘cap,env,lang,arch,gen ~  (

   instruction ( load ’a with ’b )
    with (( a ? reg )&&( b # 4 )) over (
   for x86l is (  );
   for x86m is (  );
   for armm is (  ));

   instruction ( load ’a with ’b )
    with (( a ? reg )&&( b # 2 )) over (
   for x86l is (  );
   for x86m is (  );
   for x86s is (  );
   for armm is (  ));

   instruction ( load ’a with ’b )
    with (( a ? reg )&&( b # 1 )) over (
   for x86l is (  );
   for x86m is (  );
   for x86s is (  );
   for armm is (  ));

 $ );
```

1.5.13 Compare Register Values

Requirement — Define Compare Register Values. unmet

Routines need to compare things.

```
‘cap,env,lang,arch,gen ~  (

   instruction ( compare ’a with ’b )
    with (( a ? reg )&&( b # reg )) over (
   for x86l is (   );
   for x86m is (  );
   for armm is (  ));
 $ );
```

1.5.14 Conditional Relative Branch

Requirement — Define Conditional Branch Instructions. unmet

Needed for if-then routines.

```
‘cap,env,lang,arch,gen ~  (

   instruction ( branch to ’a )
    with ( a ? bin ) over (
   for x86l is (  );
   for x86m is (  );
   for x86s is (  );
   for armm is (  ));
 $ );
```

1.6 The Application Binary Interface

Requirement — Declare a CAP ABI. partial

Each of the previous assembly language definitions encode one machine language instruction or the equivalent of one, but one instruction does not a (useful) program make. The next step up in expressiveness and organizational complexity of programming is the combining of instructions into routines and subroutines.

routine, subroutine

A routine is a collection of computational steps (e.g. machine instructions.) In a subroutine the programmer has extracted commonly used sequences of instructions and implemented them in separate routines that may be ’called’ where they otherwise might have been duplicated. This early innovation in computer science[16] drastically reduces the size of the resulting program and makes changing and improving the software easier as an error in a routine need only be modified in one place.

application binary interface, ABI

Subroutines require a convention, adhered to by the caller(s) and the subroutine that is called. Agreed upon are the usage of registers (which ones hold the parameters, and which will contain the result? which registers may the subroutine over-write and which must it preserve?) and the arrangement of items

[16] Wilkes, M. V.; Wheeler, D. J., Gill, S. (1951). Preparation of Programs for an Electronic Digital Computer. Addison-Wesley

on the stack. Such a convention for a particular architecture is its Application Binary Interface, or ABI.

The ABI will be developed in the following sub-sections:

1.6.1 *	Register Assignments.	36 — 4/4
1.6.2 *	Calling Convention.	37 — 2/2
1.6.3 *	Construction Stack Frame.	38 — 2/2
1.5.4 *	Construction Routines.	38 — 2/2

Sub-projects (sub-sections) for Section 1.5 The Application Binary Interface.

1.6.1 Register Assignments

Requirement — Declare Register Assignments. 01/19/2009 ✓

Processors differ in how the capacity and number of their registers and in how the registers may be used. Some machine language instructions may only work with specific registers. Some registers are dedicated to providing hardware support for features such as a stack or the fast processing of interrupts.

In addition to hardware restrictions, programmers may wish to reserve certain registers for certain purposes. Having one register that always contains the result of the previous calculation makes programming easier. Each architecture will have its own register usage. Register usage in cap for several architectures are as follows:

The registers in these architectures vary in size. In all of them a register is reserved as the stack pointer; the ARM also exposes the program counter as a register and maintains a link register. Each reserves several registers for arguments to subroutines. The contents of those registers may also be overwritten and used by the called routine. The result of a computation should be returned in a register used for accumulating results. Certain registers are saved by the called routine and returned unchanged to the calling routine – these are indicated by an asterisk in the above chart.

1.6.2 Calling Convention

Requirement — Describe Calling Convention. 01/19/2009 ✓

Two conventions required for subroutines are the calling convention and the stack layout. The calling convention includes which registers are saved by the caller and which are saved (or left unmodified) by the callee. A stack (or a more general heap) is required because a processor has only so many registers and yet subroutines may call other subroutines an indefinite number of times. The stack layout includes such elements as the return address for the subroutine, the previous frame pointer and arguments that could not fit in registers.

The arrangement of values on the stack for each architecture is as follows:

64-bit Position	32-bit Position	16-bit Position	Contents	Frame
(f) + 8n + 16	(f) + 4n + 8	(f) + 2n + 4	argument # n	Previous
			...	
(f) + 16	(f) + 8	(f) + 4	argument # 0	
(f) + 8	(f) + 4	(f) + 2	success address	Current
(f)	(f)	(f)	success frame	
(f) - 8	(f) - 4	(f) - 2	fail address	
(f) - 16	(f) - 8	(f) - 4	fail frame	
(f) - 24	(f) - 12	(f) - 6	Local # 0	
			...	
(f) - 8n - 24	(f) - 4n - 12	(f) - 2n - 6	Local # n	
			...	
(sp)	(sp)	(sp)	top of stack	

```
‘cap,env,lang,arch,gen ~  (

    ()
    lang,arch  /t/( "arg0"; "suca"; "sucf"; "faila"; "failf"; "loc0" )(
    x86l     |t|(  0x10 ;  0X08 ;  0x00 ;   0xF? ;   0XF? ;  0xF?  );
    x86m     |t|(  0x08 ;  0X04 ;  0x00 ;   0xF? ;   0XF? ;  0xF?  );
    x86s     |t|(  0x04 ;  0X02 ;  0x00 ;   0xF? ;   0XF? ;  0xF?  );
    armm      |t|(  0x08 ;  0X04 ;  0x00 ;   0xF? ;   0XF? ;  0xF?  );
    ppcl     |t|(  0x?? ;  0X?? ;  0x?? ;   0x?? ;   0X?? ;  0x??  );
    ppcm     |t|(  0x?? ;  0X?? ;  0x?? ;   0x?? ;   0X?? ;  0x??  );
    spkl    |t|(  0x?? ;  0X?? ;  0x?? ;   0x?? ;   0X?? ;  0x??  );
    mmix       |t|(  0x?? ;  0X?? ;  0x?? ;   0x?? ;   0X?? ;  0x?? ));
  $ );
```

1.6.3 Construction Stack Frame

Requirement — Define the Construction Stack Frame. unmet

The current stack frame contains local variables need by construction routines:

#	Local Variable in Current Frame
0	This Definition AST Reference
1	This Definition AST End + 1
2	Parent Definition AST Reference
3	Previous Definition AST Reference
4	This Definition Value End + 1

```
‘cap,env,lang,arch,gen ~  (

    ()
    lang,arch  /t/( "thisd"; "thise"; "pard"; "pred" )(
    x86l     |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    x86m     |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    x86s     |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    armm      |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    ppcl     |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    ppcm     |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    spkl    |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  );
    mmix       |t|(  0xF? ;   0xF? ;   0XF? ;  0xF?  ));
  $ );
```

construction routines execute in the context of the construction stack frame. stack frame

1.6.4 Construction Routines

Requirement — Define Construction Routines. unmet

The 'load from memory' instruction is all the system needs to define the first 'inherited' routine in xgenc. By convention in our system on the x86l when building a definition the next free value-space location is kept in the first local variable in the current stack frame (at an offset to the EBP of -8.) The following stack frame

definition merely retrieves that value.

a type for values in the accumulator:

```
   ‘lang,indp,mch,typ~([:([accval])~]; $);

((( a ? cell )&&( b ? accval )) ; bin )
lang,arch  /t/(  ’a <= ’b                                    )(
  <:: <<< arch,cpus,_r >>> ,exo
     |t|(( secr <-- mem ref via framep ofset by thise;
           mem ref via secr <-- a in accr;
           secr <-- secr + 1;
           mem ref via framep offset by thise <-- secr ));  ::>);
```

Get distance:

```
   ‘lang,indp,mch,typ~([:([binref])~]; $);

((( a ? binref )&&( b ? binref )) ; bin )
lang,arch  /t/( offset ’a to ’b                              )(
  <:: <<< arch,cpus,_r >>> ,exo
     |t|((                                              )); ::>);
```

Conjunction, addition, multiplication, left shift:

```
   ‘lang,indp,mch,typ~([:([accmop])~]; $);
   ‘lang,indp,mch~([^ accmops :~ $]; $);

( accmop )
lang,indp,mch  /t/(  "&&"; "+"; "-"; "*"; "<<" )(
accmops        |t|(   && ; +  ;  - ;  * ;  <<  ));


((( a ? accval )&&( b ? accmop )&&( c ? accval )) ; accval; bin )
lang,arch  /t/( ’a ’b ’c                                  )(
  <::  <<< arch,cpus,_r >>> ,exo
     |t|((       c;
                 stack <-- acc;
                 a;
                 tmp <-- stack;
                 acc <-- acc b tmp ];
                                       )); ::>);
```

Get Location:

```
(((  a ? binref )) ; bin )
lang,arch  /t/( addr of 'a                              )(
  <:: <<< arch,cpus,_r >>> ,exo
     |t|((                                             )); ::>);
```

check size:

```
(((  a ? binref )&&( n ? cell )) ; bin )
lang,arch  /t/( 'a # 'n                                 )(
  <:: <<< arch,cpus,_r >>> ,exo
     |t|((                                              )); ::>);
```

type check:

```
(((  a ? binref )&&( b ? cell )) ; bin )
lang,arch  /t/( 'a ? 'b                                 )(
  <:: <<< arch,cpus,_r >>> ,exo
     |t|((                                              )); ::>);
```

The above code uses an accumulator. accumulator

The value-space address of parameters of the current definition can be found offset -12 of EBP or less by 16 * (parameter number in order - 1).

These xgenc routines depend on being executed in the stack frame context of a procedure that has established local variables four bytes each in size in the following order: start of value-space for currently-being-defined item, next-free-location in value-space of currently-being-defined item, a list of starts and one-past-ends and the types and flags (total 16 bytes each) of the value spaces of the parameters of the currently-being-defined item. The values for these local variables will be initialized before the xgenc routines are executed.

1.7 Functions

Requirement — Implement Functions. partial

Most systems implementors prefer to code at a higher level of abstraction than assembly language. Also it is common to create an architecture-independent base from which to implement most of a system, leaving only a small set of low-level features to be (re-)implemented in assembly for each architecture the system is ported to. abstraction, functions

1.6a Provide an x86l base for architecture-independent function definition.
— not yet demonstrated

1.6b Provide an ARM base for architecture-independent function definition.
— not yet demonstrated

Requirements, continued.

```
‘cap,env,lang,indp ~  (
      [ base :~ $ ];
  $ );
```

`cap` requires architecture-dependent definitions to support the architecture-independent definitions.

```
‘cap,env,lang,arch,x86l ~  (
      [ base :~ $ ];
  $ );
```

The architecture independent base has a core language definition, common libraries, and repositories of optional libraries.

```
‘cap,env,lang,indp,base ~  (
      [ core :~ $ ];
  $ );

‘cap,env,lang,indp,base,core ~  (
      ^cap,env,lang,arch,base;
  $ );
```

Control flow can be built from assembly language and a convention for representing true or false as the result of a calculation.

```
‘cap,env,lang,arch,base ~  (
       [ true : ’() ([^ bool :~ acvl ]) :bin~ zero eax ];
       [ false : ’() bool :bin~ zero eax ; eax <-- eax - 0x01 ];
      ?[ if ’a then ’b else ’c
           : ’a bool
           :’’b bin
           :’’c bin
           : ’() ’b
           : ’() ’c
           : bin ~
         !a ;
         test eax ;
         jne e ;
         [ d :~ !b ;
            jmpr f ];
         [ e :~ !c ];
         [ f ] ];
      [ if ’a then ’b :~ if a then b else ([]) ];
  $ );
```

The question mark and exclamation marks create a lexical shelter for the sub-declarations of this routine (i.e. e and f) from the items referenced (a, b, and c) in order to preclude inadvertent variable capture.

Also note the forward references to d and e (they are referred to before they are defined. The parser has to perform some tricks to allow this.

Control flow in computer languages often use binary operations on true or false values.

```
‘cap,env,lang,indp,base,core ~  (
      [ not ’a    : ’a bool:’() bool:bin~
                    if a then false else true ];
      [ ’a and ’b : ’a bool:’b bool:’() bool:bin~
                    if a then b else false ];
      [ ’a or ’b  : ’a bool:’b bool:’() bool:bin~
                    if a then true else b ];
      [ ’a xor ’b : ’a bool:’b bool:’() bool:bin~
                    if a then (not b) else b ];
  $ );
```

One useful feature of most modern computer languages is the function call,

wherein the machine code for a routine is constructed in memory just once, saving space and allowing for recursion. 'callers' of the function push their parameters on the stack and then perform a transfer of execution to the location of that routine. That routine returns execution back to whichever caller when it is done.

```
‘cap,env,lang,arch,base ~  (
      ?[ makeclosurefor ’a :bin~
       ];
      ?[ makeconparamframefor ’a :bin~
       ];
      ?[ removeconparamframe :bin~
       ];
      ?[ restorestack :bin~
       ];
      ?[ end :bin~ ret 0x00
       ];
  $ );
```

With the basic machinery we can build a function call.

```
‘cap,env,lang,arch,base ~  (

      ?[ function ’a ’b ’c :bin~
          @[ d :bin~ { makeconparamframefor !a }  ;
                  !c ;
                  end ;
                  { removeconparamframe } ] ;
          [{^} {a} : {b} :bin~
            makeclosurefor !a ;
            call ;
            ? @ d ;
            restorestack
          ]
       ];

      ?[ local ’a ’b :bin~

       ];


      ?[ end with ’a :bin~
            restorestack;
            makeclosurefor !a ;
            jumptoclosuredbinstart ;
       ];

  $ );
```

Once we have functions we can use them.

```
‘cap,env,lang,indp ~  (
      [ libs :~ $ ];
      [ sntx :~ $ ];
  $ );


‘cap,env,lang,indp,libs ~  (
      [ math :~ $ ];
      [ grph :~ $ ];
      [ text :~ $ ];
      [ inet :~ $ ];
  $ );


‘cap,env,lang,indp,libs,math ~  (

       function (fibb ’n) (’n num) (
          if ( n <= 2 )
          then 1
          else ( ((fibb (n-1))-(fibb(n-2)) )
       );


       function ( f ’a ’b ’n ) (’a num : ’b num : ’n num) (
          if ( n <= 1 )
          then ( end with b )
          else ( end with ( f b (a+b) (n-1) ));
        );

       function ( fib ’n ) (’n num) ( f 0 1 n )

       function ( charcount ’s ) (’s string : ’() num ) (
         local ( ’c num : ’d string ) (


         )
       );


  $ );
```

1.8 Objects

Requirement — Implement Objects. unmet

Many systems also implement objects. objects

With the basic machinery we can build an object.

```
‘cap,env,lang,arch,base ~  (

     ‘lang,indp,mch,typ~([:([obj])~]; $);
     ‘lang,indp,mch,typ~([:([rec])~]; $);

      ?[ object ’a ’b is ’c :obj~
      ?[ part ’d ’f is ’g :obj~

       ];
       ];

      ?[ object ’a from ’e ’c :bin~

       ];

  $ );
```

Object systems often make use of inheritance. inheritance

Chapter 2

The Syntax of Syntax

Syntax gives meaning to the sequence of characters in a program text and each programming language has its own syntax. The code in the previous chapter conforms to the syntax conventions of the `i` programming language. In order to turn that program text into something that a processor can execute the system needs a definition for and a parser of that syntax.

The rules for any syntax can be written out using a language specifically designed for explaining syntax rules. ibnf is one such language. ibnf also has a syntax. This chapter starts with ibnf and then uses it and the i language to define themselves as well as to define other languages. The sections are as follows:

Sub-projects (sections) for Chapter 2: The Syntax of Syntax.

In the `cap` system `ibnf` is defined in terms of itself, and a goal of the system

is that parsers be automatically generated from their syntax definitions:

2.1 Automatically generate language parsers from BNF-style syntax descriptions. — not yet demonstrated

Requirements, continued.

A place for syntax definitions, including those of `ibnf` and of `i`, is needed in the system. Since syntax is an architecture independent concept, a syntax definition module[1] will be placed in the `indp` branch of the tree.

```
‘cap,env,lang,indp ~ ( [ sntx :~  $ ]; $);
```

BNF Backus-Naur Form[2] is a language and convention for describing syntax. `ibnf` is derived from BNF. Every complete syntax definition in `cap` (including `ibnf`) contains an `ibnf` text describing the syntax and a parsing function automatically generated from that `ibnf` text by the system.

2.1 Common ibnf Rules

rules `ibnf` consists of a sequence of rules. Many syntax definitions will share a common set of rules. These rules can be collected and defined just once.

2.2 Collect common ibnf rules.	12/18/2010 ✓

Requirements, continued.

A syntax needs a place to reside.

```
‘cap,env,lang,indp,sntx ~ ( [ common-chr :~( [ ibnf :~ $ ]; $ )]; $ );
```

[1] D.L. Parnas, (1972). On the Criteria To Be Used in Decomposing Systems into Modules. Communications of the ACM Vol. 15, No. 12 pp.1053 - 1058

[2] Knuth, Donald E. (1964). Backus Normal Form vs. Backus Naur Form. Communications of the ACM 7 (12): pp. 735736

A syntax needs a place to `start`. Syntax rules have four parts, as shown below: a rule name (`'start'`) a rule type (`'='`) a rule body (`'syntax:'`) and semicolon (`';'`) to end the rule. The `'='` for this rule means this is a composition rule, in which the semantic result for it is composed of the semantic results obtained from parsing its rule body. The colon in the rule body indicates that the semantic result is simply the result returned from parsing the sub-rule named `'syntax'`.

rule name, rule type, rule body, sub rule, semantic result, composition rule

The following ibnf definitions are all collected in `sntx,common-chr,ibnf`.

start

```
start = syntax: ;
```

Common definitions such as identifying digits in `ibnf` are substantially the same as they would be in BNF, with alternatives separated by a vertical bar (`'|'`) and with the `'?'` indicating that the this is an alternatives rule, in which the semantic result is the semantic result of the successful alternative. The semantic result of matching a character is the character itself.

digits, alternatives rule

```
dgt ? '0'|'1'|'2'|'3'|'4'|'5'|'6'|'7'|'8'|'9' ;
```

The uppercase alphabet is declared the same way.

uppercase

```
upr ? 'A'|'B'|'C'|'D'|'E'|'F'|'G'|'H'|'I'|'J'|'K'|'L'|'M'|
      'N'|'O'|'P'|'Q'|'R'|'S'|'T'|'U'|'V'|'W'|'X'|'Y'|'Z' ;
```

Likewise lowercase letters in the English alphabet:

lowercase

```
lwr ? 'a'|'b'|'c'|'d'|'e'|'f'|'g'|'h'|'i'|'j'|'k'|'l'|'m'|
      'n'|'o'|'p'|'q'|'r'|'s'|'t'|'u'|'v'|'w'|'x'|'y'|'z' ;
```

Alphabetics are uppercase or lowercase.

alphabetic

```
alp   ? upr | lwr ;
```

Alphanumerics are uppercase, lowercase, or digits.

alphanumeric

```
aln   ? upr | lwr | dgt ;
```

hex digit

A hex digit is a letter A to F or a digit.

```
hex   ? dgt |'A'|'B'|'C'|'D'|'E'|'F'|'a'|'b'|'c'|'d'|'e'|'f' ;
```

character symbols

There is a category for conventional character symbols.

```
smb ? '-'|'_'|'+'|'='|'`'|'~'|'!'|'@'|'#'|'$'|'%'|'^'|'&'|
      '*'|'('|')'|','|'.'|'<'|'>'|'?' ;
```

escaped symbols

Three specific symbols are always preceded by a backslash when included in strings in `ibnf`. Two more may be.

```
sps ? bsl | btk | bqt | bnl | btb ;
bsl / '\\' '\\' ;
btk / '\\' '\'' ;
bqt / '\\' '\"' ;
bnl / '\\' 'n' ;
btb / '\\' 't' ;
```

whitespace, scannerless parser

Whitespace characters need definition too. The `cap` system uses a scannerless parser[3] and whitespace is explicitly coded in the grammar.

```
wsc  ? ' ' | '\t' | '\n' ;
```

text collection rule, optional rule, recursive rule, sequences

Whitespace is often made of spaces in sequence. The slash indicates that this is a text collection rule, in which the semantic result of the rule is the source text over which the rule is matched. The period indicates an optional rule, and in this case the rule is recursive, allowing a sequence of one or more spaces to be met by the rule.

```
s  /  sp .s ;
```

[3] Daniel J. Salomon and Gordon V. Cormack. Scannerless NSLR(1) parsing of programming languages. SIGPLAN 89, pp 170-178. ACM Press, 1989.

Spaces can be made of space characters or tab characters. tabs

```
sp   ? ' '|'\t' ;
```

A character suitable for inclusion in a string is a number, a lowercase letter, an uppercase letter, a common symbol, or a special symbol, or whitespace. characters in strings

```
sch ? dgt | upr | lwr | smb | wsc | sps ;
```

Strings in ibnf are made of one or more suitible characters. strings of characters

```
chs / sch .chs ;
```

Positive integers are made from one or more digits in sequence. In `ibnf` the period indicates an optional element of the sequence, and rules may be recursive. positive integers

```
pnt / dgt .pnt ;
```

Alphanumeric 'symbols' are made of uppercase, lowercase, and numeric characters. alphanumeric symbols

```
als / aln .als ;
```

Note that in all the above common ibnf definitions the only rule that is referred to but not yet defined is the `syntax` rule at `start`. A complete syntax will have no undefined rules.

Another common set of definitions can be made for arithmentic expressions (defined in `sntx,common-ari,ibnf`) as follows:

common-ari needs a place to reside.

```
‘cap,env,lang,indp,sntx ~ ( [ common-ari :~( [ ibnf :~ $ ]; $ )]; $ );
```

negatable

A negatable expression is one which may be negated, and the (optional) negation is identified with a '-' sign.

```
nexpr   = .s .neg expr ;
neg     ? '-' ;
```

expression

An expression may be an addition, a subtraction, an multiplication, a division, or an item all by itself.

```
expr    ? addexpr | subexpr | mulexpr | divexpr | itmexpr ;
```

addition

The addition expression (with optional white space) is two items joined by a '+' sign.

```
addexpr = .s itm .s '+' .s itm ;
```

subtraction

Likewise the subtraction.

```
subexpr = .s itm .s '-' .s itm ;
```

multiplication

Likewise the multiplication.

```
mulexpr = .s itm .s '*' .s itm ;
```

division

Likewise the division.

```
divexpr = .s itm .s '/' .s itm ;
```

item expression

The item expression is just an item.

```
itmexpr = .s itm  ;
```

item

An item may be a variable identifier, a positive integer or a parenthetical

negatable expression.

```
    itm     ? vbl | pnt | parens ;
```

A variable is just a lowercase letter. variable

```
    vbl     = lwr ;
```

Parentheses surround a negatable expression. Nesting is thus allowed. parentheses

```
    parens  = .s '(' nexpr .s ')' ;
```

The common-ari ibnf syntax also is not a complete syntax and is designed for inclusion in some other syntax. A calculator syntax provides a good example of a complete syntax with semantics performing a useful function.

2.2 A Calculator Example

A calculator is a tool which needs a place to live:

```
‘cap,env ~  (
   [ tool :~ (
     [ calc :~ (
       [ syntax :~ $ ];
       [ intrpsmntx :~ $ ];
       [ cmplsmntx :~ $ ];
       [ test.calc :~ $ ];
   $ ) ]; $ ) ];  $ );
```

And the syntax is a sequence of newline-terminated lines:

```
    syntax  = line .s '\n' .syntax ;
```

```
def syntax_s( a, s, e, c, n ):  return ( True, s, e-s, (c, a[1], n))
```

A line may include a variable assignment but will include a negatable expression:

```
    line    = .var nexpr ;
```

```
def line_s( a, s, e, c, n ):
  print fi[s:e] + " --> " + a[2][1]
  if len(a[1])>0:  registers[a[1][1][1]] = int(a[2][1])
  return ( True, s, e-s, (c, a[2][1], n))
```

A variable assignment is just a lowercase letter followed by the equals sign:

```
    var     = .s lwr: .s '=' ;
```

The parser needs semantics. For bootstrappig we will use python:

```
def nexpr_s( a, s, e, c, n ):
  if len(a[2]) > 1:
    if a[2][1]=='-':  return ( True, s, e-s, (c, str(0 - int(a[3][1])) , n))
    else:   return ( True, s, e-s, (c, a[3][1], n ))
  else:  return ( True, s, e-s, (c, a[3][1], n ))

def plu_s( a, s, e, c, n ):  return ( True, s, e-s, (c, a[1], n ))

def itmexpr_s( a, s, e, c, n ):  return ( True, s, e-s, (c, a[2][1], n ))

def addexpr_s( a, s, e, c, n ):  return ( True, s, e-s, (c, str(int(a[2][1]) + int(a[6

def subexpr_s( a, s, e, c, n ):  return ( True, s, e-s, (c, str(int(a[2][1]) - int(a[6

def mulexpr_s( a, s, e, c, n ):  return ( True, s, e-s, (c, str(int(a[2][1]) * int(a[6

def divexpr_s( a, s, e, c, n ):  return ( True, s, e-s, (c, str(int(a[2][1]) / int(a[6

def vbl_s( a, s, e, c, n ):  return ( True, s, e-s, (c, str( registers[a[1][1]] ), n )

def parens_s( a, s, e, c, n ): return ( True, s, e-s, (c, a[3][1], n ))

def build (v,s,l,a): return 'success'
```

But a less complex syntax defines a simple calculator:

The semantic actions for a calculator interpreter are as follows:

```
ibnf semantics (
syntax  ( makenodes for arguments             ) ;
vexpr   ( setnodeval (bnft var) to (bnfv expr) ) ;
addexpr ( (bnfv opexpr) + (bnfv mdexpr)        ) ;
subexpr ( (bnfv opexpr) - (bnfv mdexpr)        ) ;
mulexpr ( (bnfv opexpr) * (bnfv mdexpr)        ) ;
divexpr ( (bnfv opexpr) / (bnfv mdexpr)        ) ;
varset  ( getnodeval (bnft var)                ) ;
numset  ( bnfv num                             ));
```

A calculator needs input:

```
a=1
b=2
c=a+b
d=(a*3)/2
d
```

The semantic actions for a calculator compiler are as follows:

```
ibnf semantics (
syntax  ( makenodes for arguments             ) ;
vexpr   ( setnodeval (bnft var) to (bnfv expr) ) ;
addexpr ( (bnfv opexpr) + (bnfv mdexpr)        ) ;
subexpr ( (bnfv opexpr) - (bnfv mdexpr)        ) ;
mulexpr ( (bnfv opexpr) * (bnfv mdexpr)        ) ;
divexpr ( (bnfv opexpr) / (bnfv mdexpr)        ) ;
varset  ( getnodeval (bnft var)                ) ;
numset  ( bnfv num                             ));
```

2.3 The ibnf for ibnf

compiler-compiler

Annotating rules with productions enables the system to automatically construct a parser/compiler for program texts written in that syntax. When `ibnf` itself is the syntax being described in `ibnf` the output of the parser/compiler is

a parser-generator or a compiler-compiler[4].

> 2.3 Declare ibnf in ibnf.
> — not yet demonstrated

Requirements, continued.

`ibnf` includes the common definitions introduced in the previous section and introduces more.

```
‘cap,env,lang,indp,sntx,ibnf,ibnf, ~ (
      cap,lang,indp,sntx,common-chr,ibnf ;
  $ );
```

The result of processing the rules of syntax for ibnf will be an ibnf parser.

```
syntax = rules: ;
```

The rules rule is defined recursively:

```
rules = rule .rules ;
```

A rule is either of a rule type or it is just a blank line.

```
rule ? incorp | accum | altern | blankline ;
```

Blank lines have optional whitespace and end in a newline character.

```
blankline / w '\n' ;
```

Each rule type has a name and a body. The alternating rule is signified by a question mark.

[4]Stephen C. Johnson. YACC: Yet Another Compiler-Compiler. Unix Programmer's Manual Vol 2b, 1979.

```
altern =  w name w '?' albody  w ';' w '\n'  ;
```

The incorporating rule is signified by a forwards slash.

```
incorp =  w name w '/' inbody  w ';' w '\n'  ;
```

The accumulating rule is signified by an equals sign.

```
accum =  w name w '=' acbody  w ';' w '\n'  ;
```

A name is made up of one or more lowercase letters.

```
name / lwr .name ;
```

Within the rule `albody` rule named items are separated by the vertical bar symbol.

```
albody = w nit .almore ;
almore =  w '|' albody ;
```

Within the rule `inbody` rule there may be multiple possibly period prefixed named items.

```
inbody = w pnit .inbody ;
```

Within the rule `acbody` rule there may be multiple possibly period prefixed or colon postfixed named items.

```
acbody = w pcnit .acbody ;
```

pnits are:

```
pnit = .'.' nit ;
```

cnits are:

```
cnit =  nit .':' ;
```

pcnits are:

```
pcnit ?  pnit | cnit | nit ;
```

A nit is a name or a character match.

```
nit ? name | cmatch ;
```

A character match is a suitable character (or escaped character) as defined in common-chr surrounded by single quotes.

```
cmatch = '\'' sch: '\'' ;
```

Alternative rule phrases in the rule body are reflected in the creation of an 'or' action in the produced rule parse function.

A rule phrase consists of one or more items.

```
phrase ::=  item. phrase. | item
     ~ ( do (callrule item)
         then (callrule phrase)) ;
```

An item may be followed by a period or a colon or may be bare. Also, an item may be a name reference or may be a symbol comprised of characters enclosed in single quotes.

```
item ::= itemp | itemc | itemb | quote. ;
        ~ match quote  ;
```

Items followed by a period remember their names and collect their productions, while Items followed by a colon remember their names and collect their text.

```
itemc ::= name. w ':'
        ~ ( callrule name; return name,extent ) ;
itemp ::= name. w '.'
        ~ ( callrule name; return name,image ) ;
```

A bare item is satisfied by a named reference to another rule, a quote item is satisfied when the literal text enclosed in quotes is matched.

```
itemb ::= name.
        ~ callrule name  ;
quote ::= '\'' chs.  '\''
        ~ chs ;
```

prod is the rule for describing productions in the body of a rule. Productions are coded in the i programming language.

```
prod ::= '~' w istmt. |
       ~ sntx,i,parse istmt  ;
```

The error rule provides a place for telling the user where things went wrong.

```
error ::= '!' w quote |   ;
```

2.4 The autogeneration of ibnf

And now to tie it all together:

```
‘cap,env,lang,indp,sntx,ibnf,parse ’a  ~ (
       sntx,ibnf,parse  sntx,ibnf,ibnf   ;
  $ );
```

The parsing function for the ibnf syntax is created by calling a parsing function for ibnf on the ibnf syntax. The parsing function used is not the parsing function being described but instead a previously existing parsing function provided by the system, much like how previously existing assembly language definitions (described in Chapter 1) were used before they were defined.

2.5 The i language in ibnf syntax

The result of parsing the ibnf description of the i syntax will be a parser for i code.

> 2.3 Declare i in ibnf.
> — not yet demonstrated

Requirements, continued.

i syntax needs a place to reside.

```
‘cap,env,lang,indp,sntx ~ ( [ i :~( [ ibnf :~ $ ]; $ )]; $ );
```

An i program at a high level description is a statement of how its binary image is constructed. The syntax is in the form of an i statement, with optional white space, and the result of parsing that statement is the image.

```
   syntax  =   w   istmt: w ;
```

Optional white space is a common feature of a syntax.

```
    w  = .wsc: .w ;
```

An i statement may be one of several things. The ibnf parser uses ordered choice to disabiguate alternatives. In order of priority they are a compound statement, a definition, an exansion, an import, a reference, or a marker, or a literal: statement

```
    istmt  ?  cmpnd | defn | expand | import | refr | mrkr | ltrl ;
```

A literal is a simple value such as a string of text or a numerical value. literal

```
    ltrl     ? istring | numval ;
```

A string is delimited by quotation marks. When a string is found in the source text a string node is created in the tree which points to the un-escaped string value in the image. string

```
    istring     = '"' chs '"' ;
```

```
def istring_s ( a, s, e, c, n ):
  return  ( True, s, e-s, (c,a[2][1].decode('string_escape'), n ))
```

With the above ibnf and semantic definitions, the following is valid i code:

```
"This is a text string!"
```

Hex numbers, big endian or little endian, may be placed directly in the image resulting from the i code (Numbers that are just numbers are not included directly in the image but may be refered to or included as parameters to other definitions.) number

```
    numval     ?  hexbnum | hexlnum | jnum ;
```

Just-numbers may be negative or positive.

```
    jnum     ?  nnum | pnum ;
```

big endian hex

Hexadecimal numbers with a capital X have a node created for them in the tree and their values are stored in big-endian format in the image.

```
    hexbnum =  '0' 'X' hexdigitsb: ;
```

little endian hex

Hexadecimal numbers with a lowercase x have a node created for them in the tree and their values are stored in little-endian format in the image.

```
    hexlnum     = '0' 'x' hexdigitsl: ;
```

hex digits

Hexadeximal digits include the regular digits and the letters A through F.

```
    hexdigitsb     =  hex hex .hexdigitsb ;
    hexdigitsl     =  hex hex .hexdigitsl ;
```

```
def hexdigitsb_s ( a, s, e, c, n ):
 x=''
 if len(a[3])>1: x=a[3][1]
 return ( True, s, e-s, (c,chr(int(a[1][1]+a[2][1],16))+x, n ))

def hexdigitsl_s ( a, s, e, c, n ):
 x=''
 if len(a[3])>1: x=a[3][1]
 return ( True, s, e-s, (c,x+chr(int(a[1][1]+a[2][1],16)), n ))
```

With the above ibnf and semantic definitions, the following two values are also valid i code (and they are equivalent):

```
0x4a3b2c1d
0X1D2C3B4A
```

A positive number may be floating point or an integer.

```
    pnum     ?  floatnum | integer ;
```

floating point

floating point numbers have a decimal point in them.

```
floatnum     /  integer '.' dfract ;
```

A decimal fraction is an integer after the dot. decimal fraction

```
dfract     =  integer:  ;
```

An integer is one or more digits. integer

```
integer     /  dgt .integer ;
```

A negative number is preceeded by a minus sign. negative numbers

```
nnum     /  '-' pnum ;
```

With the above ibnf definitions, the following values are also valid:

```
3.14
512
-25
-7.75
```

A compound statement is one or more statements (a phrase) in parentheses. compound

```
cmpnd     = '(' w iphrase: w ')' ;
```

A phrase in i is either several statements separated by semicolons or just a statement by itself. phrase

```
iphrase     = istmt w .iphrasec ;
iphrasec    = ';' w iphrase ;
```

```
def iphrase_s ( a, s, e, c, n ):  return  ( True, s, e-s, (c,a[1], a[3], n  ))
def iphrasec_s ( a, s, e, c, n ):  return  ( True, s, e-s, a[3])
```

With statements and phrases defined as they are above, statements in sequence and nested parentheses are implemented through rule recursion. Sequences like the following can be used:

```
(  3.14; "This is a string";
  512 ;
 ( -25 ; 0XFFFFFFFF);
  -7.75 )
```

definition A definition uses square brackets and has many optional parts:

```
  defn = .squa w '[' w .defname w ':' w .typeseq w '~' w .istmt w ']' ;
```

```
def defn_s ( a, s, e, c, n ):
  if(a[5]!=''):
    context[a[5][1]]=a[13]
  else:
    print "anonymous definition!"
  if len(a[5])>0: return ( True, s, e-s, ({1:'c'},"", n ))
  else: return ( True, s, e-s, ({1:'c'},a[13], n ))
```

An example:

```
(  [:~];
   [:~ "There are four" ];
   [:~ [:~ "anonymous definitions here." ]] )
```

defname The name of a definition is made from a sequence of labels that may indicate variables.

```
  defname     /  w vlabel .defname ;
```

vlabel Variables in a name are indicated with a tick-mark. Otherwise they are just labels.

```
  vlabel     /  .'\'' w label ;
```

label A label starts with an alphabetic character and may continue with alpha-

betic or numeric characters.

```
label     /  alp  .als ;
```

And so definitions can be named:

```
(  [ foo :~ 99 ];
   [ 'x frob 'y :~ "Yowza!" ];
   [ nesting :~ [ definitions :~ 0X32333435 ]] )
```

A space qualifier for a definition may provide a path to a space definition or, absent the path, may simply indicate that the definition may be discontinuous with the previous or parent definition. space qualifier

```
squa / '@' w .path ;
```

The binary image produced by the following is 'includedincluded'.

```
(   [ a :~ "included"     ];
   @[ b :~ "not included" ];
    [ c :~ "included"     ] )
```

Once a thing is defined it can be referred to.

```
refr     = path ;
```

```
def refr_s ( a, s, e, c, n ):
  if context.has_key(fi[s:e]): return ( True, s, e-s, (c, context[fi[s:e]], n ))
  else: return (False, s, e-s, (c, fi[s:e], n))
```

A path is a name or a sequence of names separated by commas. path

```
path     / iname .pathe ;
pathe    / w ',' w path ;
```

A name consists of one or more atoms separated by white space. name

```
    iname     / atom w .iname ;
```

atom The atomic part of a name may be label, a string, a number, or a compound statement.

```
    atom     ?  cmpnd | label | ltrl ;
```

With the above syntax and semantics rules the following can be done:

```
    (@[ X Y definition : ~ "second" ];
      [ X Z definition : ~ "first" ];
        0xaabbccdd;
        X Y definition )
```

marker In the i programming language, the dollar-sign is a marker for the lexical location that will accept future expansion.

```
    mrkr     = '$' ;
```

```
def mrkr_s ( a, s, e, c, n ):
  global rseq ; rseq = rseq + 1;  return ( True, s, e-s, (c, rseq , n ))
```

expand Expansion is indicated by the back-tick character followed by a path to a previously marked location, and then (following a tilde) a statement expands into the previously marked location.

```
    expand     = '`' w path w '~' w istmt ;
```

```
def expand_s ( a, s, e, c, n ): return ( True, s, e-s, (c, "Expansion!", n ))
```

The following i code shows reserving a spot for expansion and then expanding it later:

```
    (  @[ a :~ $     ];
        [ b :~ "second" ];
         `a :~ "first"      )
```

A lexical import of an item defined elsewhere in the abstract syntax tree is a path to that item prefaced by a caret. import

```
    import     = '^' w path: ;
```

When there is more than one type the types are separated by colons. typeseq

```
    typeseq     =  typeref ':' .typeseq ;
```

```
def typeseq_s ( a, s, e, c, n ): return ( True, s, e-s, (c, fi[s:e], n ))
```

A type reference... typeref

```
    typeref     = refr ;
```

```
def typeref_s ( a, s, e, c, n ): return ( True, s, e-s, (c, anot( typ( deref (a[0] ))), n ))
spcs = "
def build (v,s,l,a): return (rbuild (v,s,l,a,0))
def rbuild (v,s,l,a,d):
 print spcs[0:(d*2)] + a[len(a)-1]+" ("+str(len(a)-2)+")"
 if (a[len(a)-1]=='integer') or (a[len(a)-1]=='floatnum') or (a[len(a)-1]=='nnum') or (a[len(a)-
   o=''
 else:
   o=''
   for i in range (len(a)):
    if (i > 0) and (i < (len(a)-1)):
     if type(a[i])==type(()):
       o = o + rbuild (v,s,l,a[i],d+1)
     if type(a[i])==type(""):
       o = o + a[i]
 return o
```

2.6 Other Programming Languages

We can do syntaxes for other languages as well.

Landin, Peter J. 1966. The next 700 programming languages. Communications of the ACM 9(3):157166.

Reynolds, John C. 1972. Definitional interpreters for higher-order programming languages. In Proceedings of the ACM national conference, vol. 2, 717740. New York: ACM Press. Reprinted in Higher-Order and Symbolic Computation 11(4): 363397.

.

```
‘cap,env,lang,indp,sntx ~  (
      [ c :~ $ ];
      [ apl :~ $ ];
      [ oz :~ $ ];
      [ occam :~ $ ];
      [ basic :~ $ ];
      [ haskell :~ $ ];
      [ python :~ $ ];
      [ smalltalk :~ $ ];
      [ lisp :~ $ ];
      [ java :~ $ ];
      [ perl :~ $ ];
      [ forth :~ $ ];
      [ pascal :~ $ ];
      [ fortran :~ $ ];
  $ );

‘cap,env,lang,indp,sntx,oz ~  (
      [  decl :~ $ ];
      [  conc :~ $ ];
      [  lazy :~ $ ];
      [  mesg :~ $ ];
      [  objt :~ $ ];
      [  coco :~ $ ];
      [  rela :~ $ ];
      [  cnst :~ $ ];
  $ );
```

Chapter 3

Kernels and Runtimes

Programs expect support infrastructure to be in place.

kernel, operating system

NoMMU.

Monolithic.

Microkernel.

3.1 Interrupts and Device Drivers

Timers and X and Y, oh my.

interrupt, syscall

3.2 The scheduler

The kernel is expected to divide time among the programs that are ready to be executed.

scheduler, time slice

3.3 Memory Management

mmu, paging

A key service of operating system kernels is the management of memory.

3.4 Purpose-specific kernels

embedded

.

Chapter 4

Bootstrapping Development

Requirement — Bootstrap Development. 01/01/2009 ✓

While the cap system is intended to be self sufficient some other system was first required to interpret the source text to build it for the first time. This chapter describes the environment used to create an inital cap system and can be used to re-create it from just the source text (cap.i) if a similar Unix-like host system with some basic text processing tools (sed, awk, grep, etc.) is available.

The following sub-sections construct a bootstrapping environment for cap:

Section:		Page — ssp — req
4.1	Unpacking the source code.	78 — 1 — ✓
4.2	Producing a PDF.	79 — 1 — ✓
4.3	Building a Parser maker.	81 — 0/4 — 0/5
4.4	Constructing the System.	85 — 0/4 — 0/5
4.5	Uploading the Work in Progress.	86 — 0/4 — 0/0

Bootstrapping sections (tasks)

4.1 Unpacking the source code

Requirement — Unpack Bootstrap Files. 12/12/2009 ✓

Those programs are, of course, included in the source text for cap as follows:

```
‘cap,env ~ ( [ bootstrap :~ ( [ cap.xtrall.sh    :~ $ ];
                              [ cap.xtrfile.sh   :~ $ ];
                              [ i2l.sh           :~ $ ];
                              [ cap.bookpre.txt  :~ $ ];
                              [ pro.py           :~ $ ];
                              [ i2py.sh          :~ $ ];
                              [ s2py.sh          :~ $ ];
                              [ epi.py           :~ $ ];
                              [ cap.ibnfsmntx.sh :~ $ ];
                              [ cap.mkinterp.sh  :~ $ ];  $ ) ];  $ );
```

The first script uses the Unix shell and the second script to extract all of the bootstrapping files in this chapter as well as other places.

```
#!/bin/bash
# This is cap.xtrall.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,cap.xtrall.sh"    cap.xtrall.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,cap.xtrfile.sh"   cap.xtrfile.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,i2l.sh"           i2l.tmp
 sed -e 's/vbtm/verbatim/g' i2l.tmp >                  i2l.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,cap.bookpre.txt"  cap.bookpre.txt
 ./cap.xtrfile.sh "cap,env,bootstrap,pro.py"           pro.py
 ./cap.xtrfile.sh "cap,env,bootstrap,i2py.sh"          i2py.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,s2py.sh"          s2py.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,epi.py"           epi.py
 ./cap.xtrfile.sh "cap,env,tool,calc,syntax"           calc.ibnf
 ./cap.xtrfile.sh "cap,env,bootstrap,smtx.py"          smtx.py
 ./cap.xtrfile.sh "cap,env,tool,calc,test.calc"        test.calc
 ./cap.xtrfile.sh "cap,env,bootstrap,cap.ibnfsmntx.sh" cap.ibnfsmntx.sh
 ./cap.xtrfile.sh "cap,env,bootstrap,autosmtx.py"      autosmtx.py
 ./cap.xtrfile.sh "cap,env,bootstrap,README"           README
 ./cap.xtrfile.sh "cap,env,bootstrap,cap.mkinterp.sh"  cap.mkinterp.sh
 ./cap.xtrfile.sh "cap,env,lang,indp,sntx,common-chr,ibnf" common-chr.ibnf
 ./cap.xtrfile.sh "cap,env,lang,indp,sntx,common-ari,ibnf" common-ari.ibnf
 ./cap.xtrfile.sh "cap,env,lang,indp,sntx,i,ibnf"      i.ibnf
 ./cap.xtrfile.sh "cap,env,lang,indp,sntx,i,smtx"      i.smtx
 chmod 755 cap.*.sh ; ./cap.mkinterp.sh
```

The above script works in tandem with the following script and these two must exist on the host operating system (along with the bash, sed, awk, and pdflatex utilites that the scripts depend on.) These two scripts are small enough to type by hand into a text editor if necessary.

```
#!/bin/bash
# This is cap.xtrfile.sh

  echo "Extracting File" $1 " as " $2 from cap.i
  awk -v pats="$1 ~ " -v pat1e=":xcpt~ \"$1" -v pat2e=":xcps~ \"$1" '
   BEGIN { pout = 0 }
   $0 ~ pats { pout = 1 }
   $0 ~ pat1e { pout = 0 }
   $0 ~ pat2e { pout = 0 }
   pout > 1 {print}
   pout > 0 { pout++ }
  ' cap.i > ./$2
```

To begin bootstrapping the development process from a Unix host system which includes bash, sed and awk, place the files cap.i, cap.xtrall.sh and cap.xtrfile.sh in a directory and then execute the cap.xtrall.sh shell script.

4.2 Producing a PDF

Another bash script produces readable documentation from the cap source text in advance of the cap system being able to do so itself. In this way the system was developed using its own text markup and coding conventions.

The PDF produced by this method is not identical to but is indicative of what would be produced by the cap system and is sufficient for holistic development in absence of a native cap system.

The following pipeline of sed regexps incrementally transforms the i source text document markup strings into latex document markup and then calls pdf2latex to produce a PDF document.

```
#!/bin/bash
# This is i2l.sh which transforms i source text to latex format and then creates a pdf
cat cap.bookpre.txt cap.i cap.changelog.i | sed -e '
s/\[\:2fig...../\\begin\{figure\}\[ht\] /' | sed -e '
s/\[\:epdf . \"\(.*\)\.pdf\"..\"\(.*\)\" \]./\\includegraphics\[width=\2in\]\{\1\.pdf\
s/.\[\:figr./\\hspace\{0.5cm\} /' | sed -e '
s/..\[\:figc..Caption...../\\end\{figure\} /'| sed -e '
s/\[\].\]\;//' | sed -e 's/\"\]\;//' | sed -e '
s/\[\:para.../         /' | sed -e '
s/\[\:.\[\^cap\^para\:capml...../         /' | sed -e '
s/\[\:codh./\\begin\{minipage\}\[h\]\{.4\\textwidth\} \\begin\{code\}\\normalsize\\beg
s/\[\:code./\\noindent\\begin\{minipage\}\[h\]\{1.1\\textwidth\}  \\begin\{code\}\\nor
s/\[\:skip.\]./\\smallskip/' | sed -e '
s/\".\[\:flush.\].\"/\\hspace\*\{\\fill\}/' | sed -e '
s/\[\:capt...\(.*\)\" \]\]\;/\\end\{vbtm\}\\end\{code} \\end\{minipage\}/' | sed -e '
s/\[\:xtnd.*\~./\\noindent\\begin\{minipage\}\[h\]\{1.1\\textwidth\} \\begin\{code\}\\
s/\[\:xtni.*\"/\\begin\{minipage\}\[h\]\{.9\\textwidth\} \\begin\{code\}\\normalsize\\
s/\[\:xtnt.*\"/\\noindent\\begin\{minipage\}\[h\]\{1.0\\textwidth\} \\begin\{ptext\}\\
s/\[\:xtns.*\"/\\noindent\\begin\{minipage\}\[h\]\{1.0\\textwidth\} \\begin\{p2text\}\
s/\[\:xtne.*\"/\\begin\{minipage\}\[h\]\{.9\\textwidth\} \\begin\{example\}\\normalsiz
s/.*\[\:xcpt...\(.*\)\" \]\]\;/\\end\{vbtm\}\\end\{ptext\} \\end\{minipage\}/'| sed -e
s/.*\[\:xcps...\(.*\)\" \]\]\;/\\end\{vbtm\}\\end\{p2text\} \\end\{minipage\}/'| sed -
s/.*\[\:xcpe...\(.*\)\" \]\]\;/\\end\{vbtm\}\\end\{example\} \\end\{minipage\}/'| sed
s/.*\[\:xcpd...\(.*\)\" \]\]\;/\\end\{vbtm\}\\end\{code\} \\end\{minipage\}/' | sed '3
s/\[\:bleah...Give up converting now...\]\;/\\end\{document\}/' | sed -e '
s/.\]\;\[.\(.*\).\:sect../\\section\{\1\}/'| sed -e 's/.\]\;\[.\(.*\).:...cap.sect\:ca
s/.\[\:.\[.cap.prel\:capml...../\\section\*\{\}/' | sed -e '
s/.\[ .\(.*\). \:.\[.cap.chap\:capml.\]../\\chapter\{\1\}/' | sed -e '
s/.\].\;.\[ .\(.*\). \:chap../\\chapter\{\1\}/' | sed -e '
s/.\[\:prel../\\section\*\{\}/' | sed -e 's/\[\:bnot. .\(.*\). \] \;/\\framebox\{\\fra
s/\[\:mnot. .\(.*\). \] \;/\\marginpar\{\1\}/' | sed -e '
s/....mono..\(.*\). \] . ./\\texttt\{\1\}/' | sed -e '
s/....bold..\(.*\). \] . ./\\textbf\{\1\}/' | sed -e 's/....itlc..\(.*\). \] . ./\\emp
s/....ftnt..\(.*\). \] . ./\\footnote\{\1\}/' | sed -e '
s/.cap.doc . . \[req\:sdoc. . \]. . ..//' | sed -e '
s/\[\:stxt..cap.doc.req . ./\\fbox\{\\begin\{minipage\}\[h\]\{1.05\\textwidth\}/' | se
s/..\;\[\:scpt. .\(.*\). \]\]\;/\\end\{minipage\}\} \1/' | sed -e '
s/\[\:stxt..cap.doc.web . ./\\fbox\{\\begin\{minipage\}\[h\]\{1.05\\textwidth\}/' | se
s/..\;\[\:wend. .\(.*\). \]\]\;/\\end\{minipage\}\} \1/' | sed -e '
s/\\subsection*{\(.*\).}/\\subsection\*\{\1\}/' | sed -e '
s/\\subsection{\(.*\).}/\\subsection\{\1\}/' | sed -e '
s/\\subsection*{ }/\\subsection\*\{ \}/' | sed -e '
s/\\subsection*{ }/\\subsection\*\{ \}/' |  sed -e '
s/\[\:newp.\]./\\newpage /' > cap.latex; echo "\\end{document}" >> cap.latex; \
/usr/texbin/pdflatex cap.latex
```

i2l.sh needs a file with latex pre-configuration settings:

```
\documentclass{book}
\usepackage{amsfonts}
\usepackage{graphicx}
\usepackage{xcolor}
\definecolor{mygreen}{rgb}{0.9,1,0.9}
\definecolor{mygrey}{rgb}{1,1,1}
\definecolor{myblue}{rgb}{0.9,0.9,1}
\definecolor{myred}{rgb}{1,0.9,0.9}
\makeatletter\newenvironment{code}{%
   \noindent\begin{lrbox}{\@tempboxa}\begin{minipage}{\columnwidth}\setlength{%
   \parindent}{1em}}{\end{minipage}\end{lrbox}\colorbox{mygreen}{\usebox{\@tempboxa}}
}\makeatother
\makeatletter\newenvironment{ptext}{%
   \noindent\begin{lrbox}{\@tempboxa}\begin{minipage}{\columnwidth}\setlength{%
   \parindent}{1em}}{\end{minipage}\end{lrbox}\colorbox{myblue}{\usebox{\@tempboxa}}
}\makeatother
\makeatletter\newenvironment{p2text}{%
   \noindent\begin{lrbox}{\@tempboxa}\begin{minipage}{\columnwidth}\setlength{%
   \parindent}{1em}}{\end{minipage}\end{lrbox}\colorbox{myred}{\usebox{\@tempboxa}}
}\makeatother
\makeatletter\newenvironment{example}{%
   \noindent\begin{lrbox}{\@tempboxa}\begin{minipage}{\columnwidth}\setlength{%
   \parindent}{1em}}{\end{minipage}\end{lrbox}\colorbox{mygrey}{\usebox{\@tempboxa}}
}\makeatother
\setlength{\marginparwidth}{1.2in}
\setlength{\parskip}{0.5cm}
\setcounter{tocdepth}{0}
\let\oldmarginpar\marginpar
\renewcommand\marginpar[1]{\-\oldmarginpar[\raggedleft\footnotesize #1]%
{\raggedright\footnotesize #1}}
\begin{document}
\title{The Computer Applications Platform, 0th Edition}
\author{Copyright Charles Perkins}
\date{December 2010}
\maketitle
\thispagestyle{empty}
\tableofcontents
```

4.3 Building a Parser Maker

The first step in bootstrapping is to build a scanner for the i syntax. A python program, in several parts, will serve the purpose. Another script will piece it together for us, and then call it:

```
#!/bin/bash
# This is cap.mkinterp.sh

  cat ./common-chr.ibnf ./common-ari.ibnf ./calc.ibnf > ./tmp.ibnf
  cat ./common-chr.ibnf ./common-ari.ibnf ./i.ibnf > ./itmp.ibnf
  grep ": " tmp.ibnf  > ./auto.smtx
  grep ": " itmp.ibnf  > ./iauto.smtx
  grep "/ " tmp.ibnf  >> ./auto.smtx
  grep "/ " itmp.ibnf  >> ./iauto.smtx
  python autosmtx.py auto.smtx auto.py
  python autosmtx.py iauto.smtx iauto.py
  chmod 755 i2py.sh
  ./i2py.sh tmp.ibnf tmp1.py
  ./i2py.sh itmp.ibnf itmp1.py
  chmod 755 s2py.sh
  ./s2py.sh smtx.py tmp2.py
  ./s2py.sh i.smtx itmp2.py
  cat ./pro.py ./tmp1.py ./tmp2.py ./auto.py epi.py | sed -e '/^$/d' > parser.py
  cat ./pro.py ./itmp1.py ./itmp2.py ./iauto.py epi.py | sed -e '/^$/d' > iparser.py
  chmod 755 parser.py
  chmod 755 iparser.py

  echo "Making the interpreter and then calling it."

  python parser.py calc.txt test.out
  python iparser.py test.i test.out
  cat test.i
```

A python script prologue sets up the envirnoment for our parser:

```
import sys
fi = file(sys.argv[1]).read(); h = {}
def mark( p, l, t ): x = p +"-" + str(l);  h[x]=t; return t
def been( p, l): return h.has_key( p +"-" + str(l) )
def was(  p, l): return h[ p +"-" + str(l) ]

def cm( c, s, x ):
  if s < len(fi):
    if fi[s] == c:    return ( True, s, 1, ( x, fi[s], "cm") )
  return ( False, s, 0, (x, "", "cm") )
registers={}
context={}
rseq = 5

#fo = open(sys.argv[2], "w+")
```

We need to convert grammars of the following form:

```
dgt     ? '0'|'1'|'2'|'3'|'4'|'5'|'6'|'7'|'8'|'9' ;
pnt     : dgt .pnt ;
```

Into python functions like the following:

```
def dgt_p( s ):
  if been("dgt",s): return was("dgt",s)
  else:
    mark("dgt",s,(False,s,0,"")); met = False
    if not met: (met, ts, tl, ta) = cm( '0', s)
    if not met: (met, ts, tl, ta) = cm( '1', s)
    if not met: (met, ts, tl, ta) = cm( '2', s)
    if not met: (met, ts, tl, ta) = cm( '3', s)
    if not met: (met, ts, tl, ta) = cm( '4', s)
    if not met: (met, ts, tl, ta) = cm( '5', s)
    if not met: (met, ts, tl, ta) = cm( '6', s)
    if not met: (met, ts, tl, ta) = cm( '7', s)
    if not met: (met, ts, tl, ta) = cm( '8', s)
    if not met: (met, ts, tl, ta) = cm( '9', s)
    if not met: return mark("dgt",s,(False,s,0,""))
    else: return mark("dgt",s,(met, s, tl, ta))

def pnt_p( s ):
  if been("pnt",s): return was("pnt",s)
  else:
    mark("pnt",s,(False,s,0,"")); ok=True; ts=s; tl=0; a1=""; a2=""
    if ok: (ok, ts, tl, a1) =  dgt_p   ( ts+tl )
    if ok: (ack, ts, tl, a2) = pnt_p ( ts+tl )
    if ok: return mark("pnt",s,(True, s, ts+tl-s, pnt_s( a1+a2 )))
    return mark("imt",s,(False,s,0,""))
```

Another script will effect that transformation by sending the ibnf source text through a pipeline of sed regular expressions:

```
#!/bin/bash
# This is i2py.sh
  echo "Creating scanner for" $1 " as " $2
```

First rejoin lines broken at an alternative:

```
sed -e 's/: / /g' $1  |sed -e 's/ = / : /g' |sed -e 's/ \/ / : /g' | sed '/|$/N;s/\n *
```

change = to : and append p to ibnf definitions and definition references:

```
/ [?:] /s/\([a-z]\) /\1_p /g'   |  sed -e "
```

Next create match-by-ascii-number functions for several special characters

and a general character match function call for the rest:

```
s/'\\\\\\\\'/ cm(chr(92) ,s) /g"| sed -e "s/'\\\\''/ cm(chr(39) ,s) /g" | sed -e "
s/'\\\\\"'/ cm(chr(34) ,s) /g"  | sed -e "s/'\\\\t'/ cm(chr(9) ,s) /g"  | sed -e "
s/'\\\\n'/ cm(chr(10) ,s) /g"   | sed -e "s/'\(.\)'/ cm('\1' ,s) /g"| sed -e "
```

Next put spaces around character literal ibnf items:

```
s/'\(.\)'/ '\1' /g"        |  sed -e '
```

Turn ibnf alternatives into bash else-if clauses:

```
s/ | / ( s )insertnewline    if not met: (met, ts, tl, ta ) = /g' |  sed -e '
```

Turn ibnf definitions into bash functions:

```
s/^ *\([a-z]*_p\) *\([?:]\) *\(.*\); *$/def \1( s )\2\3}\2/' |  sed -e '
```

Prepend an if keyword for ibnf alternative bash functions:

```
s/( s )?/\( s ):insertnewline  if been("!1!",s): return was("!2!",s)~:~/'  |  sed -e '
s/~:~/insertnewline  else:insertnewline~:~/'  |  sed -e '
s/~:~/    mark("!3!",s,(False,s,0,(c,"","")))); met = Falseinsertnewline~:~/'  |  sed -e '
s/~:~/    if not met: (met, ts, tl, ta) = /'  |  sed -e '
```

Create "if not met" statements for ibnf alternative bash functions:

```
s/}?/ ( s )insertnewline    if not met:  return mark("!4!",s,(False,s,0,(c,"","")))}?/'  |  sed
s/}?/insertnewline    else:        return mark("!5!",s,(met,s,tl,ta))/'   |  sed -e '
s/^def \(.*\)_p\(.*\)!1!\(.*\)!2!\(.*\)!3!\(.*\)!4!\(.*\)!5!\(.*\)$/def \1_p\2\1\3\1\4\1\5\1\6\1
s/,s) *( s )/,s)/g'  |  sed -e '
s/_p ( s )/_p( s )/g'  |  sed -e '
s/_p  ( s )/_p( s )/g'  |  sed -e '
```

Put newlines in sequence definitions:

```
s/def \(.*\)_p( s ):\(.*\)}:/def \1_p( s ):!1!"\1"!2!"\1"!3!"\1"!4!\2!5!"\1"!6!\1!7!"\
s/_p /_p ( ts+tl )insertnewline    !=!/g'        |  sed -e '
s/ ,s) / ,(ts+tl))insertnewline    !=!/g'        |  sed -e '
s/!1!/insertnewline  if been(/'        |  sed -e '
s/!2!/,s): return was(/'        |  sed -e '
s/!3!/,s)insertnewline  else:insertnewline    mark(/'        |  sed -e '
s/!4!/,s,(False,s,0,(c,"","X"))); ok=True; ts=s; tl=0; a={0: (c,"","X")}; n=0insertnew
s/!=! */!=!/g'        |  sed -e '
s/!=!!5!/if ok: return mark(/'        |  sed -e '
s/!6!/,s, /'        |  sed -e '
s/!7!/_s( a, s, ts+tl) )insertnewline    return mark(/'        |  sed -e '
s/!8!/,s,(False,s,0,(c,"","")))/'        |  sed -e '
s/!=!\./if ok: n=n+1; (nok, ts, tl, a[n]) = /g'        |  sed -e '
s/!=!/if ok: n=n+1; (ok, ts, tl, a[n]) = /g'        |  sed -e "
```

Put semicolons after parsing calls and match calls in sequences then remove the colons:

```
#/):{/s/\(_p\)/\1 ; /g"      |  sed -e "
#/):{/s/\(_p\) ;  ( )/\1 ( )/g"      |  sed -e "
#/):{/s/\('.'\)/\1 ; /g"      |  sed -e '
#s/):{/) {/'                  |  sed -e '
s/passfail_p/passfail/'      |  awk '
```

Finally, place the newlines and write the file:

```
{ gsub ("insertnewline", "\n") }1' | sed -e '
s/def \(.*\)s ):/def \1s, c ):/g'  | sed -e '
s/    if ok: n=n+1;\(.*\))/    if ok: n=n+1;\1, a[n-1][0])/g'  | sed -e '
s/    if ok: return\(.*\)) )/    if ok: return\1, a[n][0]) )/g'  | sed -e '
s/    if not met: (met\(.*\))/    if not met: (met\1, c)/g' | sed -e '
s/mark("\(.*\)",s, \(.*\)) )/mark("\1",s, \2,"\1") )/g'  | sed -e '
s/mark("\(.*\)",s,(False\(.*\)))/mark("\1",s,(False\2))/g'  >  ./$2
```

Generate simple semantics:

```
import sys

fi = open(sys.argv[1], "r")
fo = open(sys.argv[2], "w+")
line = fi.readline()
params = "_s( a, s, e, c, n ):  return ( True, s, e-s, (c,"
tail = "], n ))"

while line:
 x = line.find(" /")
 if x > 0:
     print >> fo, "def " + line[0:x].strip() + params + "fi[s:e" + tail
 x = line.find(" =")
 if x > 0:
   y = line.count(":")
   if y == 1:
     t = line[x+2:].strip(); u = t[0:len(t)-1];  n=0; q=False
     for c in u:
       if c==':': v = n
       if (c!=' ') and not q: n = n + 1; q = True
       if (c==' ') and q: q = False
     print >> fo, "def " + line[0:x].strip() + params + "a["+ str(v) + tail
 line = fi.readline()
```

Another script will tranform grammer semantics into shell code operations:

```
#!/bin/bash
# This is s2py.sh

echo "Creating semantic actions for" $1 " as " $2
#if [ ! -f "./$1" ]
#then
#  echo " Error ------- $1 file not found."
#else
#  sed 's/^\(.*\)$/# \1/' $1 > ./tfa
#  sed 's/^# *\([a-z]*\) *(\(.*\)).;/ \1_s ( ) { \2 }/' ./tfa > ./tfb
#  cp ./tfb ./$2
#fi
cp $1 $2
```

A parser implementation needs some basic functionality, and a command to kick it all off:

```
#fo.write(start(s).o)
#fo.close()


(v,s,l,a) = start_p( 0, {} )
if v:
  print "Parsed "+a[len(a)-1]+" OK"
  print "tree:"
  print a
  print "result:"
  print build (v,s,l,a)
  print "definitions:"
  print context
else: print "Failed to Parse"
```

A calculator syntax will stand in for the i syntax to test things out:

The semantic actions for elements of a grammer are coded separately. The semantic actions for i.ibnf are as follows:

```
#!/bin/bash
# This is cap.ibnfsmntx.sh
```

We need a README file for upload of the source code to other repositories:

```
This is a README file for the Computer Applications Platform,
which is meant to be a self-sustaining computing environment
for commodity computers. The CAP system is intended to provide
features corresponding to compilers, operating systems, and
applications.

         This is revision 0 of the software,
          THE SYSTEM IS NOT YET FUNCTIONAL.

See cap.pdf for an exploration of the systems goals, status,
techniques, and implementation.

To bootstrap the system (as far as it is currently implemented)
in a Unix environment with bash, sed, awk, python, place the files
cap.i, cap.xtrfile.sh, and cap.xtrall.sh in a directory, make the
shell scripts executable, and then execute cap.xtrall.sh

After bootstrapping the system, if you have latex installed on your
host system you can execute the i2l.sh script to produce the cap.pdf file.

The system is released under the MIT free software license:

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OTHER DEALINGS IN THE SOFTWARE.
```

4.4 Constructing the System

Now the system executables can be created:

4.5 Uploading the Work in Progress

Another script uploads the source text and pdf file to a server:

Chapter 5

Documents

The system prints its own documentation and has text markup and domain specific languages for vector images and diagrams.

Chapter 6

User Interface

How the user interacts with the system.

Chapter 7

Networking

The whole is worth more than the sum of its parts.

Chapter 8

Applications for the Computer Platform

cap exists to get useful work done.

Chapter 9

Distributing the System

Few successful programming projects are the isolated product of a single individual. Frequently programming projects have web sites to coordinate the work of diverse contributors and to distribute the product of their efforts.

cap includes a template for project coordination web sites. Templates for other kinds of sites may be added later.

```
‘cap,env,serv,web,template ~  (
   [ devprj ’a: a ? website ~ $ ];
  $ );
```

For deployment with actual content the template needs a site configuration.

```
‘cap,env,serv,web,site ~  (
   [ caphub : website ~ $ ];
  $ );
```

The coordination web site template is composed of items that may be in-

cluded in pages, and the pages themselves.

```
‘cap,env,serv,web,template,(devprj ’a) ~  (
   [ items :~ $ ];
   [ pages :~ $ ];
  $ );
```

A vibrant development web site needs a welcoming overview home page, up-to-date news content, appropros helpful information, a place to discuss the project, a way to get the product, and a way to contribute enhancements The development project web site template includes six top-level pages, one for each of these areas.

```
‘cap,env,serv,web,template,(devprj ’a),pages ~  (
   [ home       ’b: b ? htdata ~ $ ];
   [ news       ’b: b ? htdata ~ $ ];
   [ help       ’b: b ? htdata ~ $ ];
   [ discuss    ’b: b ? htdata ~ $ ];
   [ download   ’b: b ? htdata ~ $ ];
   [ contribute ’b: b ? htdata ~ $ ];
  $ );
```

The pages have a common skeletal structure. In addition, Every page will have a banner at the top and a navigation menu to the left.

```
‘cap,env,serv,web,template,(devprj ’a),items ~  (
   [ pageskel ’d :~ $ ];
   [ banner :~ a,bannertext ];
   [ navmenu :~ ( "<table>"; [ menuitems :~ $ ]; "</table>")];
  $ );
```

The text (and graphics) of the banner will be supplied when the template is applied to an actual project web site.

All of the pages have a banner at the top, a navigation menu to the left, and a main content area.

```
‘cap,env,serv,web,template,(devprj ’a),items,(pageskel ’d) ~  (
   [ prologue :~ ("<html><head><title>"; d,title; "</title></head><body>") ];
   [ topsect :~ ( "<table><tr><td>"; banner; "</td></tr><tr><td><table><tr>")];
   [ leftsect :~ ( "<td>"; navmenu; "</td><td>") ];
   [ rightsect :~ d,content ];
   [ epilogue :~ ("</td></tr></table></td></tr></table></body><html>") ];
  $ );
```

The home page is first in the navigation menu.

```
‘cap,env,serv,web,template,(devprj ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">Home</a></td></tr>";
  $ );
```

In addition to the the navigation menu and the banner, the home page has its own title and contains static content.

```
‘cap,env,serv,web,template,(devprj ’a),pages,(home ’b)~  (
   items,(pageskel [:~(
     [ title :~ (a,name; " home") ];
     [ content :~ a,hometext ] )]);
  $ );
```

News is similarly constructed.

```
‘cap,env,serv,web,template,(devprj ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">News</a></td></tr>";
  $ );

‘cap,env,serv,web,template,(devprj ’a),pages,(news ’b)~  (
   items,(pageskel [:~(
     [ title :~ (a,name; " news" )];
     [ content :~ a,newstext ] )]);
  $ );
```

Same for Help.

```
‘cap,env,serv,web,template,(devprj ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">Help</a></td></tr>";
  $ );

‘cap,env,serv,web,template,(devprj ’a),pages,(help ’b) ~  (
   items,(pageskel [:~(
     [ title :~ (a,name; " help" )];
     [ content :~ a,helptext ] )]);
  $ );

‘cap,env,serv,web,template,(devprj ’a),pages,(discuss ’b)~  (
   items,(pageskel [:~(
     [ title :~ (a,name; " discuss" )];
     [ content :~ a,discusstext ] )]);
  $ );

‘cap,env,serv,web,template,(devprj ’a),pages,(download ’b)~  (
   items,(pageskel [:~(
     [ title :~ (a,name; " download" )];
     [ content :~ a,downloadtext ] )]);
  $ );

‘cap,env,serv,web,template,(devprj ’a),pages,(contribute ’b)~  (
   items,(pageskel [:~(
     [ title :~ (a,name; " contribute" )];
     [ content :~ a,contributetext ] )]);
  $ );

‘cap,env,serv,web,site,caphub ~  (
   serv,web,template,(devprj [:~(
   [ name :~ "caphub" ];
   [ bannertext :~ "Internet Hub for the Computer Applications Platform" ];
   [ hometext :~ "Welcome to the Computer Applications Platform distribution and contr
   [ newstext :~ "Not much news yet." ];
   [ helptext :~ "Good luck!" ];
   [ discusstext :~ "The discussion boards are not yet open." ];
   [ downloadtext :~ "Download here." ];
   [ contributetext :~ "Upload here." ])]);
  $ );
```

Computer Applications Platform coordination web site

banner

The web page links the above items together.

Chapter 10

Interfacing to Legacy Data

A maximally useful system will interoperate well with existing, entrenched systems. For example, databases are a cornerstone of corporate information technology, and may not be trivially replaced but must instead be interfaced to. cap can be used to create a private intranet site which accesses legacy data using templates created in the previous chapter. A corporate employees benefits tracking intranet interface to SQL stored benefits data will provide an example.

```
‘cap,env,serv,web,template ~  (
   [ intra ’a: a ? website ~ $ ];
  $ );
```

For deployment with actual content the template needs a site configuration:

```
‘cap,env,serv,web,site ~  (
   [ bene : website ~ $ ];
  $ );
```

As with the development project web site, the benefits intranet site template

is composed of items that may be included in pages, and the pages themselves.

```
‘cap,env,serv,web,template,(intra ’a) ~  (
   [ items :~ $ ];
   [ pages :~ $ ];
  $ );
```

A corporate intranet site has a different focus than a public development project and the structure of the template reflects this. A default home page presents login and status information, and employee, supervisor, and administrator pages provide different views on the intranet information.

```
‘cap,env,serv,web,template,(intra ’a),pages ~  (
   [ home      ’b: b ? htdata ~ $ ];
   [ empview   ’b: b ? htdata ~ $ ];
   [ superview ’b: b ? htdata ~ $ ];
   [ adminview ’b: b ? htdata ~ $ ];
  $ );
```

The pages have a common skeletal structure. In addition, Every page will have a banner at the top and a navigation menu to the left.

```
‘cap,env,serv,web,template,(intra ’a),items ~  (
   [ pageskel ’pagedata :~ $ ];
   [ banner :~ a,bannertext ];
   [ navmenu :~ (  "<table>"; [ menuitems :~ $ ]; "</table>")];
  $ );
```

The text (and graphics) of the banner will be supplied when the template is applied to an actual project web site.

All of the pages have a banner at the top, a navigation menu to the left, and a main content area.

```
‘cap,env,serv,web,template,(intra ’a),items,(pageskel ’pagedata) ~  (
   [ prologue :~ ("<html><head><title>"; pagedata,title; "</title></head><body>") ];
   [ topsect :~ ( "<table><tr><td>"; banner; "</td></tr><tr><td><table><tr>")];
   [ leftsect :~ ( "<td>"; navmenu; "</td><td>") ];
   [ rightsect :~ pagedata,content ];
   [ epilogue :~ ("</td></tr></table></td></tr></table></body><html>") ];
  $ );
```

The home page is first in the navigation menu.

```
‘cap,env,serv,web,template,(intra ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">Home</a></td></tr>"
  $ );
```

In addition to the the navigation menu and the banner, the home page has its own title and contains static content.

```
‘cap,env,serv,web,template,(intra ’a),pages,(home ’b)~  (
   items,pageskel ([:~(
     [ title :~ (a,name; " home") ];
     [ content :~ a,hometext ] )]);
  $ );
```

Employee Data is similarly constructed.

```
‘cap,env,serv,web,template,(intra ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">Employee</a></td></tr>"
  $ );

‘cap,env,serv,web,template,(intra ’a),pages,(empview ’b)~  (
   items,pageskel ([:~(
     [ title :~ (a,name; " employee" )];
     [ content :~ a,emptext ] )]);
  $ );
```

Same for Supervisors.

```
‘cap,env,serv,web,template,(intra ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">Supervisor</a></td></tr>"
  $ );

‘cap,env,serv,web,template,(intra ’a),pages,(superview ’b)~  (
   items,pageskel ([:~(
     [ title :~ (a,name; " supervisor" )];
     [ content :~ a,supertext ] )]);
  $ );
```

Same for Administrators.

```
‘cap,env,serv,web,template,(intra ’a),items,navmenu,menuitems ~  (
    "<tr><td><a href=\"/\">Administrator</a></td></tr>"
  $ );

‘cap,env,serv,web,template,(intra ’a),pages,(adminview ’b)~  (
   items,pageskel ([:~(
     [ title :~ (a,name; " administrator" )];
     [ content :~ a,admintext ] )]);
  $ );
```

And the text of the pages must be provided:

```
‘cap,env,serv,web,site,bene ~  (
   cap,env,serv,web,template,intra ([:~(
   [ name :~ "bene" ];
   [ bannertext :~ "Intranet site for corporate employee benefits tracking" ];
   [ hometext :~ "Welcome to the employee benefits web site." ];
   [ emptext :~ "Nothing for employees to see yet." ];
   [ supertext :~ "Nothing for supervisors to see yet." ];
   [ admintext :~ "Nothing for Administrators to see yet." ])]);
  $ );
```

Corporate intranet benefits tracking database.

banner

The web page links the above items together.

Chapter 11

Adapting to the world

Internationalization, Localization, etc.

Chapter 12

Appendix I – Requirements

Claims and Fulfillment.