Urbit ~

The technical problem

- the high-level deterministic computer
  - official definition
    - entire lifecycle defined by a single frozen function
    - lifecycle semantics defined at the programmer level
  - existing approximations
    - machine VM: inherently low-level
    - JS, JVM, etc: transient, and not quite frozen
    - Lisp, Smalltalk machines: no functional definition
  - user experience: integrated OS/interpreter/DB
  - when a deterministic computer hits an undecidable problem?
- kelvin versioning
  - decreases by integers to absolute zero; Urbit is 5K

The human problem (1)

- the Internet as a client-server network has won
  - (HTTP = ATDT) $\Longrightarrow$ (FB = AOL)
- the Internet as a peer-to-peer network has failed
  - new wide-area protocols can no longer be introduced
    - even SMTP survives only by inertia
  - no one wants to self-host on a personal Linux server
    - Linux is layer 7 of the Internet
  - the Linux/Internet platform is unsalvageable as a P2P network

The human problem (2)

- the old platform is a fine substrate to layer over
    - on the client side, the browser already did this
- there's a plausible need for a new platform
    - we don't know that people don't want personal servers
    - we just know they don't want personal Unix servers on the Internet
- the obstacle to the personal server is admin cost
    - technical simplicity is a plausible therapy
- this "browser for the server side" is a clean slate
    - since we're layering over both the OS and the network

The one-function computer

- the simplest network: a global broadcast ethernet
  - routing is an optimization (content-centric networking)
  - packets are facts; the event log is a list of facts heard
- the simplest computer: a packet transceiver
- two ways to define a one-function computer:
  - lifecycle function: L(input history) → resulting state
  - transition function: T(input event, state) → (output actions, new state)
- any practical L will converge to some T
  - output in a lifecycle function is an optional hint
  - a lifecycle function can define a boot sequence

Practical implementation

- event sourcing is popular these days
    - good tools for low-latency reliable logs (Kafka)
    - snapshot and append-only log is the normal DB design
    - every packet is a transaction, finalized when complete
- non-packet I/O can be event-sourced (libuv)
- decidability is a heuristic problem
    - interrupt a console; time out a packet
    - the log is an existence proof of computability
- nondeterminism feeds back into the event stream

Let’s try it in Lisp

- it’s easy to define a lifecycle function in Lisp
  - (defun lifecycle (log) ((car log) (cdr log)))
    - the first event is the function, the rest of history is the argument
      - of course we still have to write the function…
- now all we need is the one true perfect frozen Lisp
  - a lifecycle function makes extreme demands on interpreter precision
  - probably no “one-stage” interpreter can satisfy these demands
  - two stages: axiomatic untyped VM, user-level typed compiler
- lambda puts high-level features in the axioms
  - symbols, functions, variables, scopes, are all user-level features

The Urbit stack

- Nock: typeless, frozen interpreter
  - defined in 200 words, on a (readable) T-shirt
- Hoon: pure, strict, typed functional language
  - does not use category theory
  - compiles its own compiler to Nock
- Arvo: nonpreemptive operating system
  - written in Hoon
  - defines a transition function T(event, state) -> (actions, new state)
  - defines a referentially transparent global namespace
  - interprets and sends untrusted, unreliable network packets
  - can update everything except Nock over the wire

Nock ideals

- a “functional assembly language”
- a Lisp without high-level affordances
  - symbols, variables, scope, syntax, etc
- no cyclic or infinite data structures
  - acyclic strict data is much easier to persist and transport
- efficient execution strategy
- fits on a T-shirt
- obviously perfect and will never need to change

Nock concepts

- a value in Nock is a *noun*
- a noun is an *atom* or a *cell*
  - an atom is an unsigned integer of any size
  - a cell is an ordered pair of any two nouns
    - cells are strict and acyclic and compare by value
- Nock is a function `*[subject formula] → product`
  - the *subject* is the data; the *formula* is the function; the *product* is the result
  - any error produces nontermination, bottom, ⊥

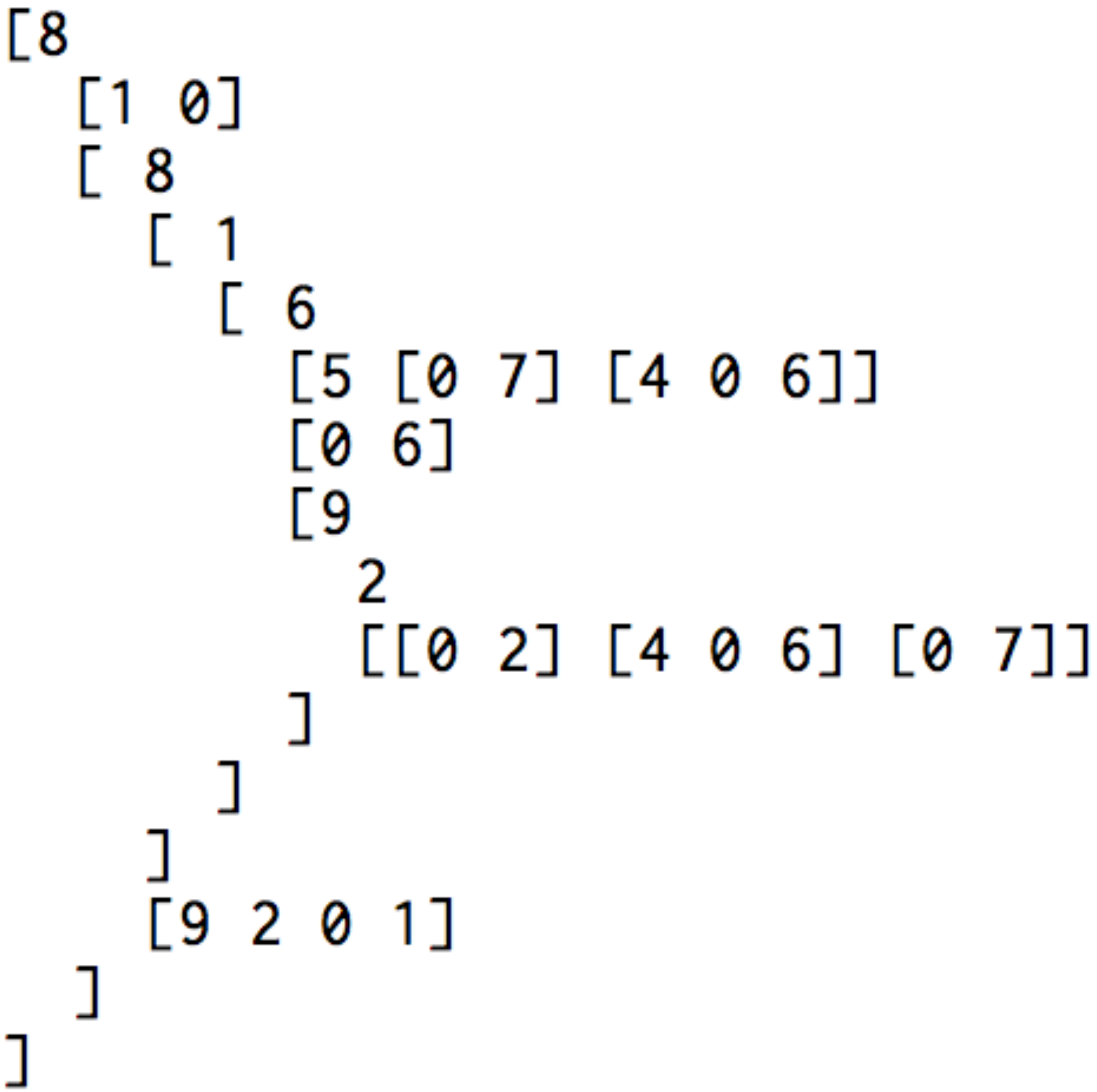
Nock spec (intrinsics)

```
?[a b]           0
?a               1

+[a b]           +[a b]
+a               1 + a

=[a a]           0
=[a b]           1
=a               =a

/[1 a]           a
/[2 a b]         a
/[3 a b]         b
/[(a + a) b]     /[2 /[a b]]
/[(a + a + 1) b] /[3 /[a b]]
/a               /a
```

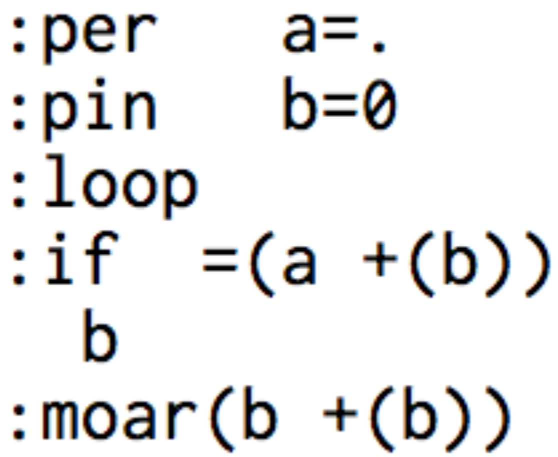
Nock spec (instructions)

```
*[a [b c] d]     [*[a b c] *[a d]]

*[a 0 b]         /[b a]
*[a 1 b]         b
*[a 2 b c]       *[*[a b] *[a c]]
*[a 3 b]         ?*[a b]
*[a 4 b]         +*[a b]
*[a 5 b]         =*[a b]

*[a 6 b c d]     *[a 2 [0 1] 2 [1 c d] [1 0] 2 [1 2 3] [1 0] 4 4 b]
*[a 7 b c]       *[a 2 b 1 c]
*[a 8 b c]       *[a 7 [[7 [0 1] b] 0 1] c]
*[a 9 b c]       *[a 7 c 2 [0 1] 0 b]
*[a 10 [b c] d]  *[a 8 c 7 [0 3] d]
*[a 10 b c]      *[a c]

*a               *a
```

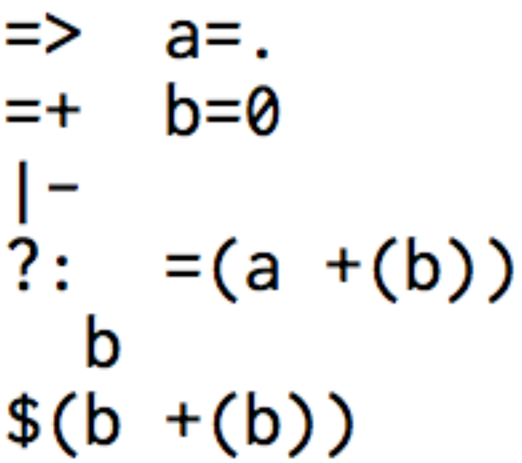
Decrement in Nock and Hoon



```
[8
  [1 0]
  [ 8
    [ 1
      [ 6
        [5 [0 7] [4 0 6]]
        [0 6]
        [9
          2
          [[0 2] [4 0 6] [0 7]]
        ]
      ]
    ]
    [9 2 0 1]
  ]
]
```



```
:per    a=.
:pin    b=0
:loop
:if  =(a +(b))
  b
:moar(b +(b))
```



```
=>  a=.
=+  b=0
|-
?:  =(a +(b))
  b
$(b +(b))
```

Nock optimization

- O(n) decrement is nifty, but not practical
- solution: a sufficiently smart interpreter
  - just recognize any decrement formula, and execute it efficiently
    - also add, multiply, and all other common intrinsics
- wait, we don’t have to recognize *every* decrement
  - just the decrement in the standard library
- solution: hint-register and match important functions
  - these *jets* are like software device drivers
  - user code remains pure, but declares a semantic identity
  - an interpreter which recognizes this identity can optimize it

Hoon ideals

- compiler compiles itself from source to Nock
  - does *not* have to be frozen; anything above Nock must self-update
- pure, strict, higher-order typed functional language
- transformation to Nock is simple, like C to assembly
- requires no particular mathematical aptitude
  - and does not use category theory
- encourages lower-order, more imperative style
  - DSLs considered harmful
- still almost as expressive as Haskell

Hoon concepts

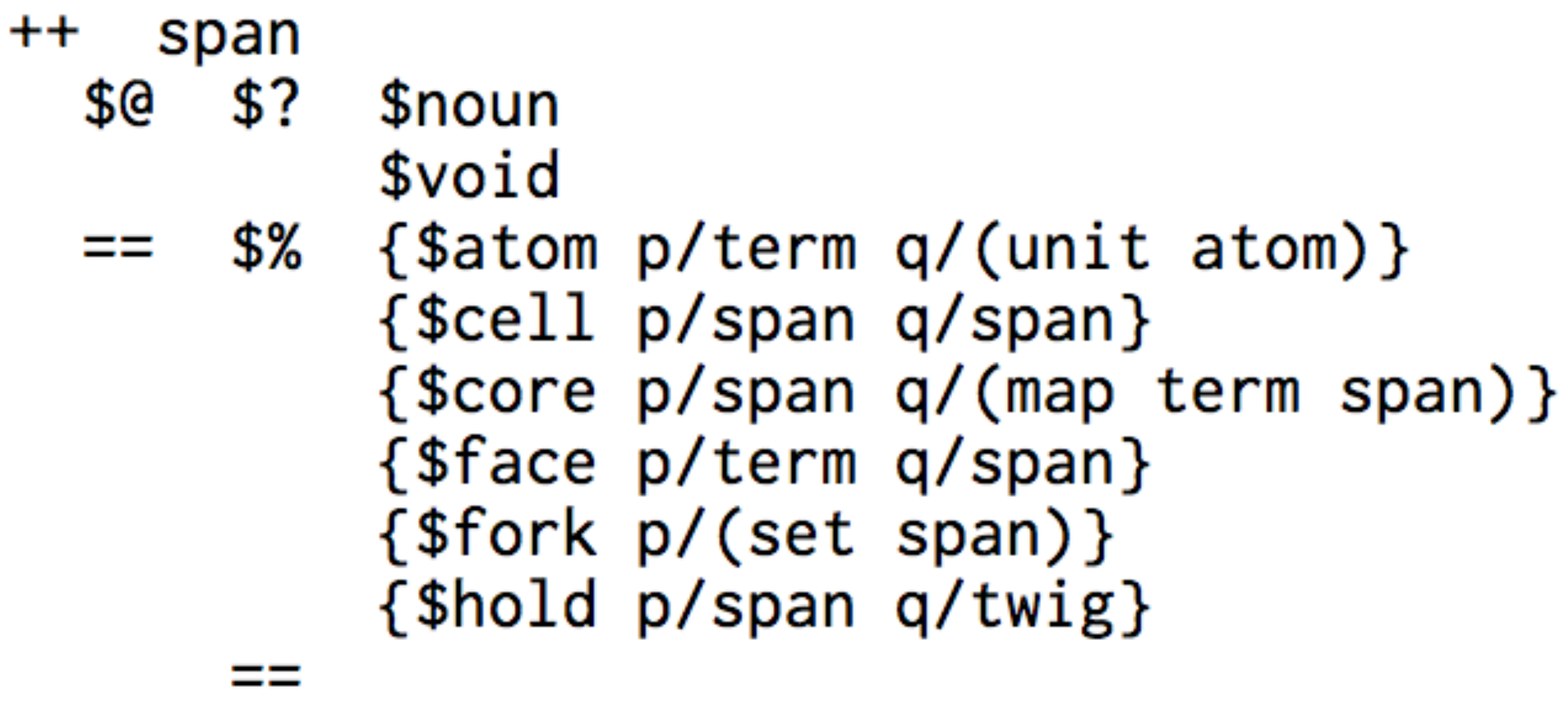
- Hoon is a typed macro assembler for Nock
  - type inference and code generation combined are 1.500 lines of Hoon
- Computes `[subject expression] → product`
  - “subject-oriented programming”
- the Hoon compiler is a parser and a generator
  - the parser (`vast`) computes `source → expression`
  - the generator (ut) computes `[type expression] → [type formula]`
    - its input is the subject type (domain) and the expression
    - its output is the product type (range) and the Nock formula
- Hoon infers only forward, without unification
  - a (slightly) less intelligent inference algorithm is a UI win
  - it’s good to coerce the product of any entry point, just for doc reasons

Never say type

- Learn the secret language of Hoon
    - an expression (AST noun) is a `twig`
    - a type (as in set of nouns) is a `span`
    - a type (as in constructor/declaration) is a `mold`
    - a type (as in MIME type) is a `mark`
- Hoon is a pure prototype language
    - there is no syntax for a span; it is only defined as the range of a computation
- A `mold` is a normalizing function on an arbitrary noun
    - a true `mold` is idempotent, so `=((mold x) (mold (mold x)))`
    - the only time we actually *call* a `mold` is to validate network data

Basic span concepts

- twigs are boring once you understand spans
- `mold` for a slightly simplified `span`:



```
++  span
  $@  $?  $noun
          $void
  ==  $%  {$atom p/term q/(unit atom)}
          {$cell p/span q/span}
          {$core p/span q/(map term span)}
          {$face p/term q/span}
          {$fork p/(set span)}
          {$hold p/span q/twig}
      ==
```

- missing only: aliases, variance and typeclasses

Unboring spans: `$atom`

- `{$atom p/term q/(unit atom))}`
  - if `q` is set, `u.q` is the only atom in the range (constant)
  - `p` is an aura, a symbol which describes units/presentation/constraint
    - auras are unenforced conventions
    - auras specialize by extension right
      - `@t` for UTF-8 text, `@ta` ASCII, `@tas` ASCII with symbol constraint
      - `@s` for signed integer, `@sx` for signed hexadecimal integer
    - auras can be cast upward or downward, but not across

Unboring spans: `$core`

- `{$core p/span q/(map term twig)}`
  - a core is a `[battery payload]` cell
  - p is the span of the payload
  - q is a table of computed attributes, or *arms*
    - the battery is the tree of the arm formulas
    - the subject of each arm is the core
  - single namespace searches battery first, then payload
- a core is the general case of functions and objects
  - a function in Hoon is a `gate`: a special case of `core`
    - a `gate` has one nameless arm (`$`) and a payload `[sample context]`
  - a method in Hoon is an arm which produces a `gate`
  - an object in Hoon is a core whose arms are all methods

Advanced span theory

- the `$hold` form is manual laziness
  - but also lets conservative worklist algorithms prune recurrent traverses
- branch conditions are analyzed for type inference
  - this allows classic functional pattern matching
- two kinds of polymorphism: variance and genericity
  - polymorphism is about compatibility of mutated cores (Liskov substitution)
  - variance: does mutant payload match original payload?
    - collect all four: covariance, contravariance, invariance, bivariance
  - genericity: does battery formula work with mutant payload?
    - generic (wet) arms expand inline like macros

Syntax design

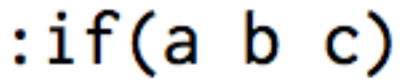
- Hoon syntax is `twig` syntax
- `twig` syntax is functionally complex and looks gnarly
    - but everyone who learns it is surprised at how easy it was
- Hoon solves three problems with functional syntax
    - expressions grow downward and to the right
        - solution: backstep indentation
    - either terminator piles or significant whitespace
        - solution: self-terminating form
    - hard to distinguish special forms from symbols
        - solution: no macros, marked keywords / runes

Twig structure

- a twig is the AST expression
  - which compiles to a Nock formula, which defines a function of the subject
- any cell `[twig twig]` is also a `twig`
  - which constructs the cell of its subtrees, like Lisp `cons`
  - Hoon is tuple-centric, not list-centric, because types work
- any other twig is a tagged union, `[stem bulb]`
  - the head of the twig is an atom, its `stem`
  - the stem is a 2-4 byte `term` (ASCII symbol)
  - the shape of the tail depends on the stem
    - but usually a tuple or list of twigs

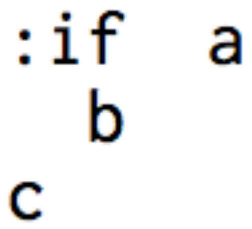
Regular forms, flat and tall

- every `stem` defines its own `bulb`
  - most are 1-ary, 2-ary, 3-ary or 4-ary tuples; some are n-ary lists
  - every `stem` with a tuple/list `bulb` has a regular form
- regular forms come in two forms: *flat* and *tall*
  - a flat twig is delimited by parens, and separates subtwigs by one space:



```
:if(a b c)
```

  - a tall twig has no delimiters, and separates subtwigs by 2+ spaces:

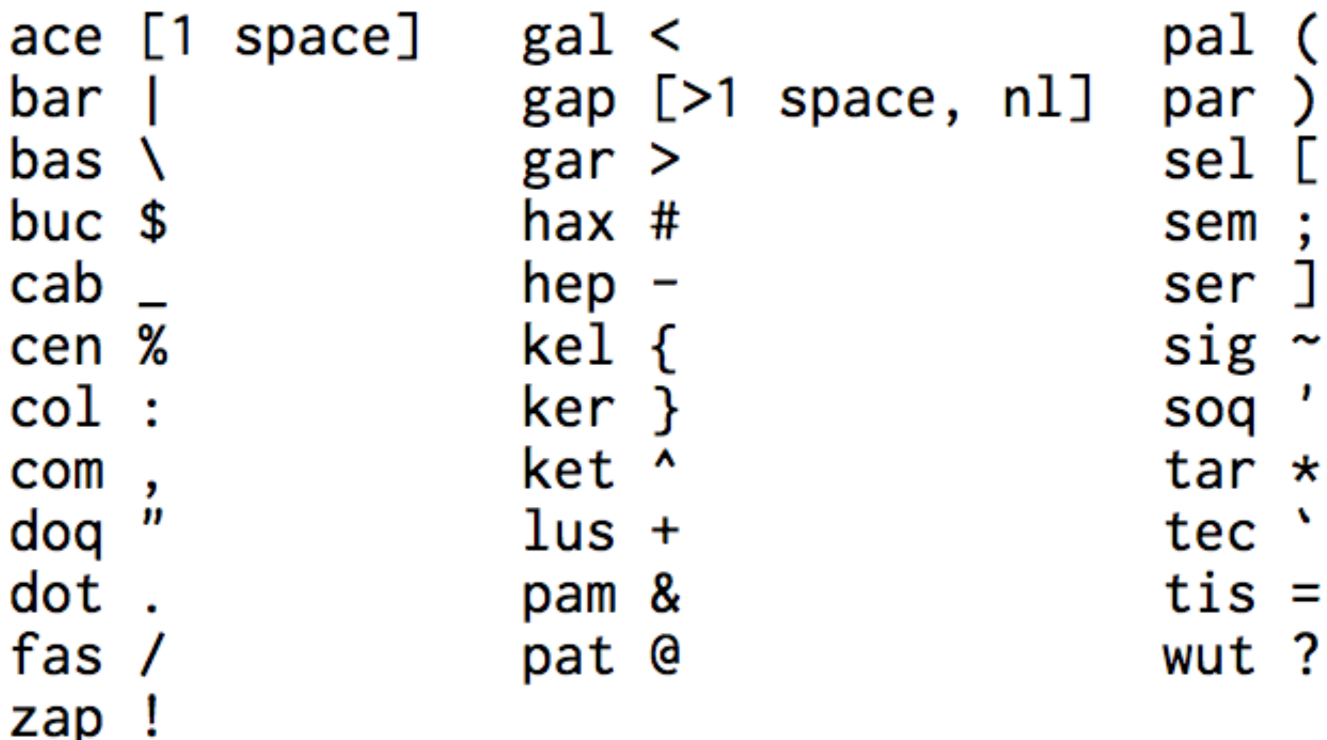


```
:if  a
  b
c
```

- goal: look like a procedural expression-statement mix

Runes and irregular forms

- irregular form: always flat, always ASCII, and always a `twig`
- a regular form can use a keyword or a *rune*
  - keyword is colon-prefixed: `:if(a b c)`
  - rune is a digraph: `?:(a b c)`
    - first character defines role (eg, all ? runes are conditionals)
- ASCII reloaded:



```
ace [1 space]   gal <                pal (
bar |           gap [>1 space, nl]   par )
bas \           gar >                sel [
buc $           hax #                sem ;
cab _           hep -                ser ]
cen %           kel {                sig ~
col :           ker }                soq '
com ,           ket ^                tar *
doq "           lus +                tec `
dot .           pam &                tis =
fas /           pat @                wut ?
zap !
```

Two forms of FizzBuzz

```
:gate  end/atom
:var   count  1
:loop
:cast  (list tape)
:if  =(end count)
   ~
:cons
  :if  =(0 (mod count 15))
    "FizzBuzz"
  :if  =(0 (mod count 5))
    "Fizz"
  :if  =(0 (mod count 3))
    "Buzz"
  "{<count>}"
:moar(count (add 1 count))
```

```
|=  end/atom
=/  count  1
|-  ^-  (list tape)
?:  =(end count)
   ~
:_  $(count (add 1 count))
?:  =(0 (mod count 15))
  "FizzBuzz"
?:  =(0 (mod count 5))
  "Fizz"
?:  =(0 (mod count 3))
  "Buzz"
"{<count>}"
```

Arvo concepts

- the Arvo kernel is a Hoon core
    - with a fixed battery exporting a few arms
    - including a transition function T(event) → (actions, new core)
    - the kernel ABI is frozen at the Nock level
        - so any event can replace Arvo or even Hoon
        - as long as it can build a core that looks the same to Nock
- Arvo proper is ~600 lines
    - internal event cascade with causal stack
    - global typed referentially transparent namespace
    - load and reload kernel modules (vanes), like baby kernels

Arvo vanes (kernel modules)

- `%ames`, encrypted packet network
- `%behn`, timers
- `%clay`, revision-controlled typed filesystem
- `%dill`, console
- `%eyre`, HTTP client/server with reactive apps
- `%ford`, functional build system
- `%gall`, applications

Urbit identity concepts

- “Urbit” just means the Nock/Hoon/Arvo stack
    - and more specifically the PKI / identity model
    - “an urbit” means one event history / state / instance/ node, with one identity
        - identity creation is part of the boot process
    - the identity is a `ship`, the instance is a *pier*
- one system solves:
    - human-memorable cryptographic identity
    - P2P packet routing address
    - base of global immutable namespace path
- assault on Zooko’s triangle
    - trivial solution: identity is 128-bit public-key hash
    - tradeoff: memorable, but not meaningful

A civil address space

- phonemic base-256 makes numbers memorable
    - 0x802a.136d in `@ux`; .128.42.19.109 in `@if`; `~patnub-tarlud` in `@p`
- a 128-bit “wild” ship is called a `comet`
    - but shorter numbers are more memorable, hence more valuable
- a 64-bit “civil” address space can overload it
    - 64-bit ship: *moon*; `~padfes-sopden-difmyl-padtul`; connected device
    - 32-bit ship: *planet*; `-difmyl-padtul`; human being
    - 16-bit ship: *star*; `~mocryg`; minor infrastructure
    - 8-bit ship: *galaxy*; `~num`; major infrastructure
- each tier is initially signed by its half-width parent
    - but signs its own key update; renewal is revocation
    - ships can be traded like bitcoin, but low-frequency “spends” don’t need a blockchain
    - galaxies are “premined” in the kernel source

On purpose and hindsight

- but was it really necessary to invent all this crap?
- a personal server is a social server
  - when two humans socialize, they should exchange messages directly
  - and not fall back into the degenerate case of a central server
- centralized programming is always easier
  - in today's infrastructure it's orders of magnitude easier
- the criterion: *difficulty of distributed programming*
- a true personal server must solve this problem
  - some impersonal servers wouldn't mind as well

Programmer experience

- dereference the global immutable typed namespace
- application state is permanent, no database required
- update source code propagates reactively via revision control
    - application type changes require typed state adapters
- two messaging patterns, `poke` and `peer`
    - no abstraction leakage versus local communication
    - `%eyre` lets web clients poke and peer over HTTP
- a `poke` is a typed, transactional message
    - exactly-once delivery (even though it's impossible)
    - no return data if transaction succeeds
    - message is automatically validated
        - backward-compatible protocol updates cause no errors in a live network
    - passed to the receiving program as a typed event
    - end-to-end acknowledgments mean single error mode
    - sender queues until message delivered or rejected
    - P2P network delivers anywhere
    - authenticated and encrypted, of course
- a `peer` creates a subscription which streams typed diffs

System status

- 30,000 lines of Hoon (Hoon, Arvo, all vanes, and basic apps)
- open source and patent-free
- urbit.org
  - served by Urbit (behind nginx :-)
- github.com/urbit
- somewhere between alpha and beta quality
  - small live network, “used in anger”, working shell and chat apps
  - Arvo internal interfaces mostly stable
  - global flag day (“continuity breach”) every few months
- documentation historically sucks, but getting better
  - Hoon documentation is now adequate
  - next phase is Arvo documentation
- ready for self-hosted address-space crowdsale