Hints and Principles for Computer System Design

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MSRA Faculty Summit
October 30, 2014

Overview

A 30-year update of my 1983 *Hints for Computer Systems*

These are hints, often not consistent or precise

- Just a few principles
- Hints *suggest*, principles *demand*
  - No nitpicking allowed

STEADY by **AID**

- **What**: **S**imple, **T**imely, **E**fficient, **A**daptable, **D**ependable, **Y**ummy
- **How**: **A**pproximate, **I**ncremental, **D**ivide & conquer, …

There are three rules for writing a novel. Unfortunately, no one knows what they are.
—Somerset Maugham

You got to be careful if you don't know where you're going, because you might not get there.
—Yogi Berra

The quest for precision, in words or concepts or meanings, is a wild goose chase.
—Karl Popper

What: Goals

Simple
Timely (to market)*
Efficient
Adaptable*
Dependable
Yummy*

*More important today

STEADY

Need tradeoffs—You can't get *all* these good things

[Data is not information,] Information is not knowledge, Knowledge is not wisdom, Wisdom is not truth, Truth is not beauty, Beauty is not love, Love is not music and Music is THE BEST" —Frank Zappa

How: Methods

Approximate
- **Good enough**
- Loose specs
- Lazy/speculative

Incremental
- **Compose (**indirect, virtualize)
- **Iterate**
- Extend

Divide & conquer
- **Abstract with interfaces**
- Recursive
- Atomic
- Concurrent
- Replicated

AID

Oppositions

Precise vs. **approximate** software. Which kind is yours?

Precise: Get it right (avionics, banks, Office)

Approx: Get it soon, make it cool (search, shopping, Twitter)

Features↔TTM↔speed↔cost↔dependability↔coolness

F^6: Fancy↔ First ↔ Fast ↔ Frugal ↔ Faithful ↔ Fun

Is it right? ↔ does it run? ↔ will it sell? ↔ can it evolve?

Adaptable: evolving ↔ fixed, monolithic ↔ extensible

Dependable: reliable ↔ flaky; stochastic ↔ deterministic

Coordinate Systems and Notation

Choose the right coordinate system

- Like center of mass for dynamics, or eigenvectors for matrices
- Example: State as *being* vs. *becoming*—(name→value) map *vs.* log
  - Bitmap/display list; redo-undo log; replicated state machine
- Example: Function as code *vs.* table *vs.* overlay
  - Table: Cache code results. Overlay: write buffer, search path

Use a good notation

- Vocabulary: Types and methods.
- Syntax: Domain-specific languages
- Primitives: Relations include functions, graphs, tables, state transitions

A point of view is worth 80 points of IQ. —Alan Kay

Science is not there to tell us about the Universe,
but to tell us how to talk about the Universe. —Niels Bohr

Write a Spec

At least, write down the state—Abstract state is *real*

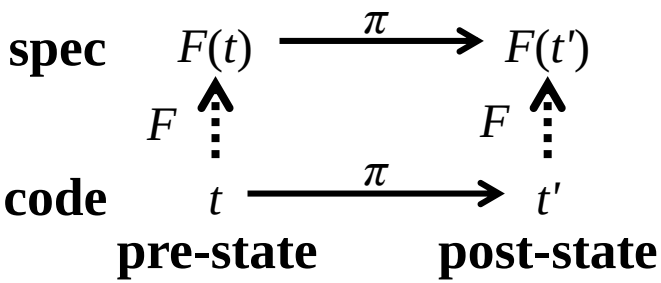
Example: File system state is `PathName→ByteArray`

Then, write down the interface actions (APIs),

which ones are external, and what each action π does

Next, write the *abstraction function F* from code to spec

Finally, show that each action π preserves *F*:



The purpose of abstracting is not to be vague,
but to create a new semantic level in which one can be absolutely precise. —Dijkstra

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STEADY

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STEADY: Simple–KISS

Why is it important? Because we can't do much

Simple is hard, often not rewarded—"That's obvious."

- Why didn't computer scientists invent the web?
- Why *did* we invent the Internet?

Simple enough: I can still understand it

- But what happens when the system evolves?
- Only abstraction and interfaces can save you

How? Interfaces, atomic (D), extensible (I), good enough (A)

Less is more. —Browning
Everything should be as simple as possible, but no simpler. —Einstein
I'm sorry I wrote you such a long letter; I didn't have time to write a short one. —Pascal

STEADY: Timely—Keep it real

Good enough is good enough

- The web is successful because it doesn't have to work.
- Many errors are not fatal
  - They can be retried, automatically (end-to-end) or by the user
  - They can be undone
  - They don't matter much: Look at Amazon's web pages

Learn what customers really want—Iterative development

How? Focus (D), extensible, iterate (I), good enough (A)

The best is the enemy of the good. —Voltaire
If you don't think too good, don't think too much. —Ted Williams
Perfection must be reached by degrees; she requires the slow hand of time. —Voltaire

And the users exclaimed with a laugh and a taunt,
"It's just what we asked for but not what we want." —Anonymous

STEADY: Efficient–Reduce waste

Two aspects: for the implementer, and for the client

- Not unrelated: the client wants it fast and cheap enough

Efficient *enough*, not optimal

Understand what's important for *you*

- People cost to administer? Standardize, automate.
- Hardware cost to provide a stable service? Write tight code.
- NRE/TTM? Use big components, burn hardware, good enough

How? Concurrent (D), shared, deltas (I), lazy (A)

An efficient program is an exercise in logical brinkmanship. —Dijkstra
It's cheaper to be networked than standalone: continuous updates, shared data, and availability through replication. —Phil Neches
I see how it [the phone] *works. It rings, and you have to get up.* —Degas
That, Sir, is the good of counting. It brings everything to a certainty, which before floated in the mind indefinitely.—Samuel Johnson

STEADY: Adaptable–Plan for success

Evolution/scaling: Successful systems live a long time

- Machines get faster. load increases, features get added :
  - 2014 PC = 100,000 × Xerox Alto, Web grew from 100 users to 10^9

Incremental update: Big things change a little at a time

- Databases; web indexes; complex/dynamic displays; routing
- Autotuning: Manual is slow, unreliable and expensive

Fault-tolerance: Crashes, errors, bugs are unavoidable

How? Interfaces (D), extensible, distributed (I), loose (A)

Success is never final . —Churchill
One man's constant is another man's variable. —Alan Perlis
APL is like a diamond; Lisp is like a ball of mud. —Joel Moses

STEADY: Dependable–Don't say 'Sorry'

Reliable: Gives the right answer (safe).

Available: Gives the answer promptly (live).

Secure: Works in spite of bad guys

How much dependability? It depends on the customer

- British railways: $1B/life saved
- Phone system: much less now than in 1980

Often dependable **undo** is the most important thing

How? Replicate, partition (D), simple (S), redo log (I)

But who will watch the watchers? She'll just begin with them and buy their silence. —Juvenal
The unavoidable price of reliability is simplicity. —Tony Hoare

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AID

AID: Divide & Conquer

Abstract with interfaces: Divide by **difference**

- Limit complexity, liberate parts. TCP/IP, file system, HTML
- Platform/layers. OS, browser, DB. X86, internet. Math library
  - Platform as simplifier: Transactions, garbage collection
- Declarative. HTML/XML, SQL queries, schemas
  - The program you think about takes only a few steps
- Synthesize a program from a partial spec. Excel Flashfill
  - Signal + Search → Program

Don't tie the hands of the implementer. —Martin Rinard

Civilization advances by extending the number of important operations which we can perform without thinking about them. Operations of thought are like cavalry charges in a battle — they are strictly limited in number, they require fresh horses, and must only be made at decisive moments. —Whitehead

AID: Divide & Conquer

Abstract: Divide by **difference**

Recursive: Divide by **structure**. Part ~ whole

Quicksort, DHTs, Path names. IPV6, file systems

Replicate: Divide for **redundancy**, in time or space

Retry: End to end (TCP). Replicated state machines.

Concurrent: Divide for **performance**

Stripe, stream, or struggle: BitTorrent, MapReduce

If you come to a fork in the road, take it. —Yogi Berra

To iterate is human, to recurse divine. —Peter Deutsch

AID: Incremental

Compose relations, functions, processes, components

Join, connect, fork

Indirect: Control name→value mapping

- Virtualize/shim: VMs, NAT, USB, app compat, format versions
- Network: Source route → IP addr → DNS name → service → query
- Symbolic links, register renaming, virtual methods, copy on write

Iterate design, actions, components

Redo: Log, replicated state machines (state as becoming)

Undo. File system snapshots, transaction abort

Scale. Internet, clusters, I/O devices

Extend. HTML, Ethernet

Any problem in computing can be solved by another level of indirection. —David Wheeler
Compatible, adj. Different. —The Devil's Dictionary of Computing

AID: Approximate

Good enough. Web, search engines, IP packets

- Often non-deterministic
- Eventual consistency. DNS, Dynamo, file/email sync

Loose coupling: Springy flaky parts. Email, Fedwire

Brute force. Overprovision, broadcast, scan

- Reboot: Crash fast
- Strengthen (do more than is needed): Redo log, coarse locks

Relax: small steps converge to desired result.

- Routing protocols, daily builds, exponential backoff

Bottleneck performance analysis—back of the envelope

Hints: Trust, but verify.

Lazy/speculative: bet on future. OCC, write buffer, prefetch

I may be inconsistent. But not all the time.—Anonymous

Summary

Hints and principles—suggest *vs.* demand

STEADY by **AID**

What: **S**imple, **T**imely, **E**fficient, **A**daptable, **D**ependable, **Y**ummy

How: **A**pproximate, **I**ncremental, **D**ivide & conquer

If you only remember three things:

Keep it simple

Abstract with interfaces

Write a spec

One last hint: Get it right

If I have seen further than others, it is because I have stood on the shoulders of giants. —Schoolmen of Chartres, via Newton

The only thing new in the world is the history you don't know. —Harry Truman

History doesn't repeat, but it rhymes. —Mark Twain