Understanding Code: The Scientific Method for Approaching Code

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Systems and Security Lunch (SSL) Presentation

Systems Research Timeline

- Idea! Requires implementation/evaluation
- Identify system with design amenable to your goals
- Unpack (*amazing looking*) system
- Build and test new system
- **Read through system's code**
- Modify (distinctly less amazing) existing code
- Debug, `goto pain`...iterate
- (9 months and much blood later)
  Evaluate *shiny* new (disgusting-looking) system
- Publish world-changing research

Goal: Productivity in a Large Code-base

Today: how to effectively read through system's code

- **scientific method** for reading code
- the onion model for code traversal

Analogy...

Speed Dating: The typical method

Getting to know someone (Surface questions)

- Hey, how you do'in
- How 'bout that weather?
- . . . and those red sox/nationals/sport team?

A reliable way to find a compatible partner?

Speed Dating: The tactless method

Just ask better (uncomfortable) questions? (Deep questions)

- How do you vote?
- What's your credit score?
- What are your dreams?
- What are your values?
- `diff values actions | wc -l`
- `diff dreams direction | wc -l`

Done! 6 questions to determine the rest of your life!

A reliable way to find a compatible partner?

Give up! Succumb to biology

Forget dating, go to the *dive bar*!

#1 and only criteria: *Superficial Attractiveness*

A reliable way to find a compatible partner?

Dating Works (?)

$$\begin{aligned} \text{Surface questions} &\neq \text{good compatibility test} \\ \text{Deep questions} &\neq \text{good compatibility test} \\ \text{Superficial attractiveness} &\neq \text{good compatibility test} \\ ??? &= \text{good compatibility test} \end{aligned}$$

I hear people get married...

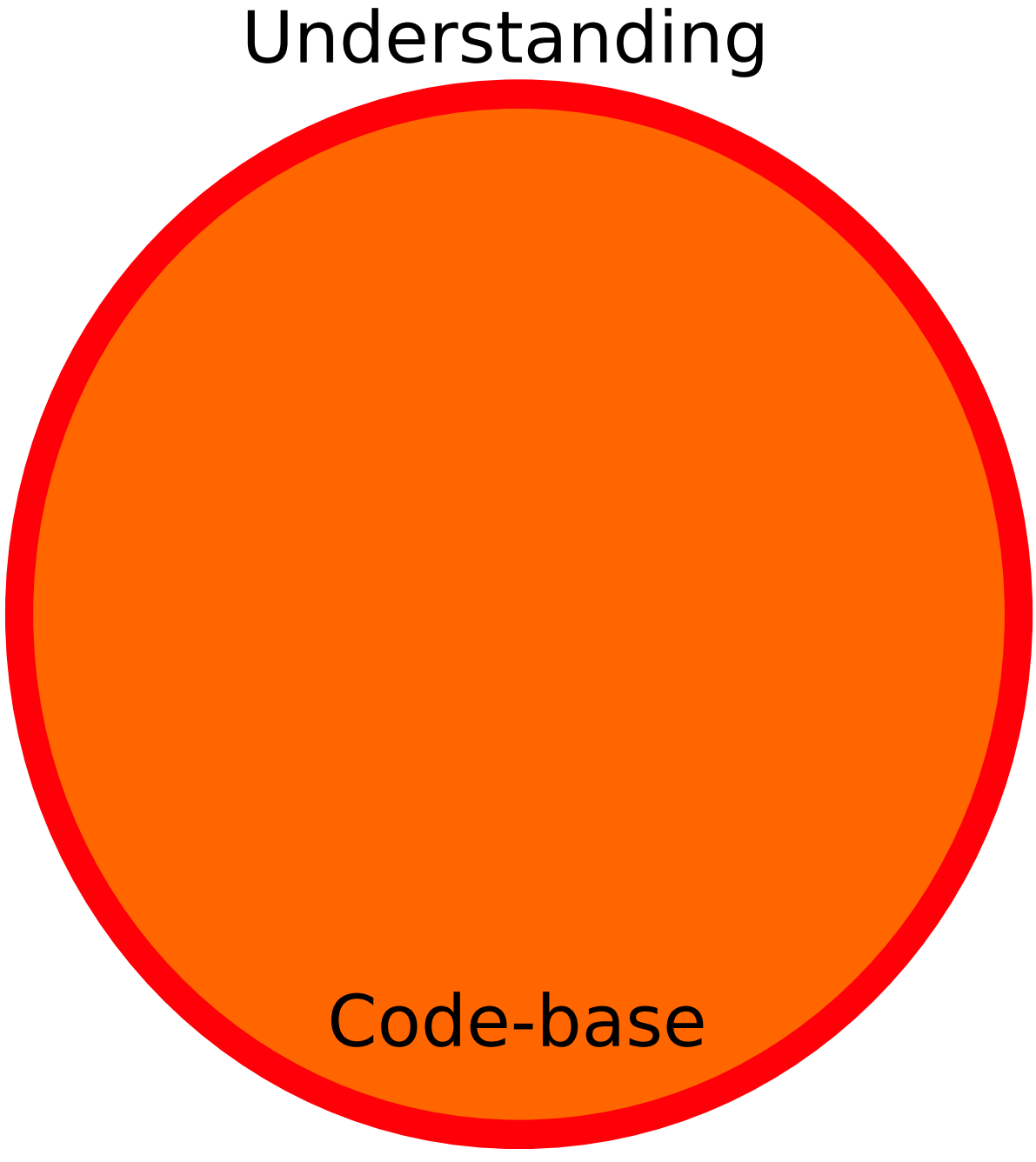
Analogy

Getting to know a partner	=	Understanding a system
Surface questions	=	"reading the code"
Deep questions	=	characterizing behavior (experiments)
Superficial attractiveness	=	design documents (diagrams, papers, concepts) . . . window-dressing and lies

These things *are important*

. . . but not great for *understanding* a system

Understanding Code: A diagram



The Speed Dating of Reading Code

Some superficial attractiveness:

- high-level structure: *design* documents
- paper-level understanding

Some small talk:

- directory/build structure
- code structure
  - more variant in C/Python/..., less-so in Java/Haskell
- code rules/conventions (style guides)
- Most important: naming conventions

Aside: efficiency is important – learn your tools

- lxr (web-based cross references)
- TAGS, GTAGS
- grep
- emacs (iswitch, M-/, M-. w/ TAGS, goto-line, C-s+C-w)

Getting to know you: Example

CBUFs= COMPOSITE predictable, efficient data passing

- data shared $\text{comp}_0 \longleftrightarrow \text{comp}_1$ in 300 cycles

Examples

- `doc/design/*` = high-level design
- `src/components/include/cbuf.h` = common-case functions
- inlined functions = fast-path
- `src/components/interface/cbuf_c/*.c` = non-fast-path, client code
- `src/components/interface/cbuf_c/cbuf_c.h` = manager interface
- `src/components/implementation/cbuf_c/naive/*` = manager/server code
- `cbuf_*` = client-facing interface functions

Reading code: Naive approach

What is your algorithm for reading code?

Reading code: Naive approach

Depth-First Search (DFS)

1. inspect function
2. see function calls?
    - no called functions? return to previous fn
3. see called function, goto 1

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This is small talk

- mechanical, non-engaging

Reading code: Naive approach

Depth-First Search (DFS)

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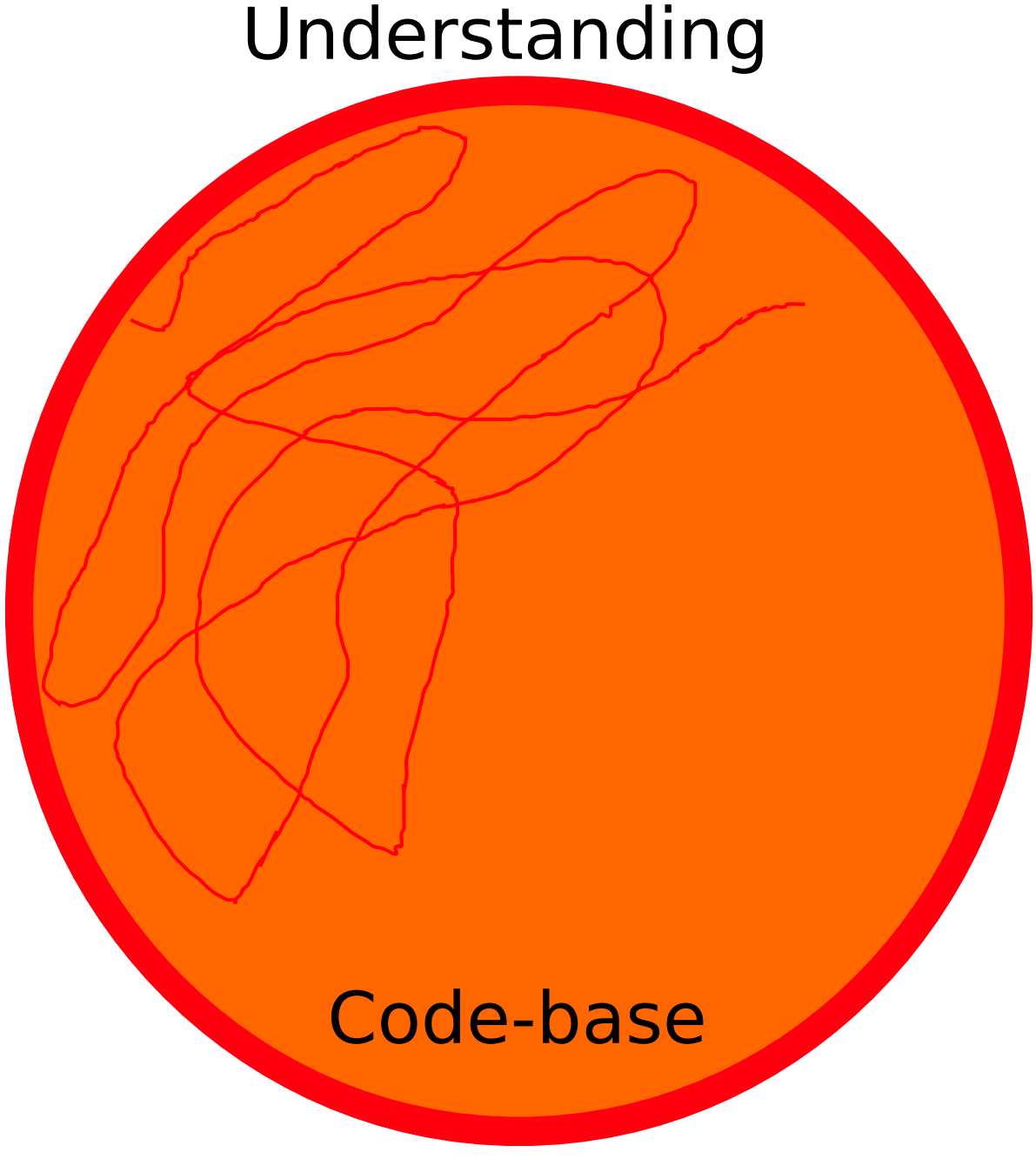
Why doesn't this work? Better way?
How about just use BFS?

DFS $\neq$ Understanding



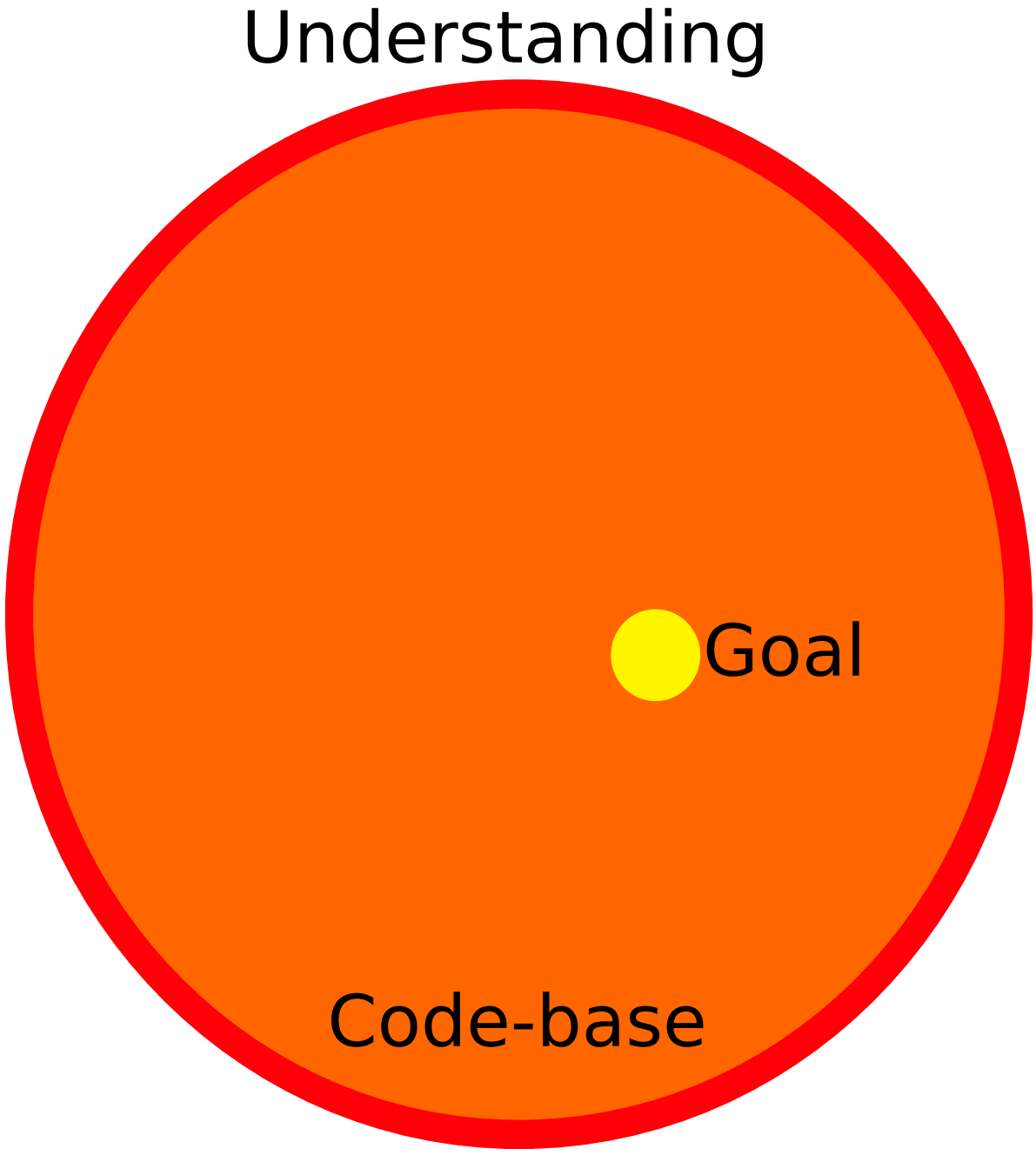
Scientific Method for Reading Code

1. **Goal**: What are you trying to learn?
   - "how CBUFs efficiently shared between components?"
   - no goal = waste of your time

2. **Hypothesis**:
   A strong statement about the current code of interest
   - "CBUFs are optimized for a cached common-case to avoid invocations"
   - "the cached case is handled only in `cbuf.h`"
   - "the non-cached case handed off to `*_slow` functions"
   - "`*_slow` functions call `cbuf_mgr` → maps CBUFs"

3. Confirm/refute hypothesis
   - confirm = next hypothesis → goal
   - refute = back up, reformulate hypothesis

Understanding Code: Goal-directed



Hypothesis: Guided, Deepening Understanding

Ideal hypothesis stated

- relative to goal
- relative to high-level design
- informed by *behavior/tests*

hypothesis = f(design, goal, behavior, understanding of code)

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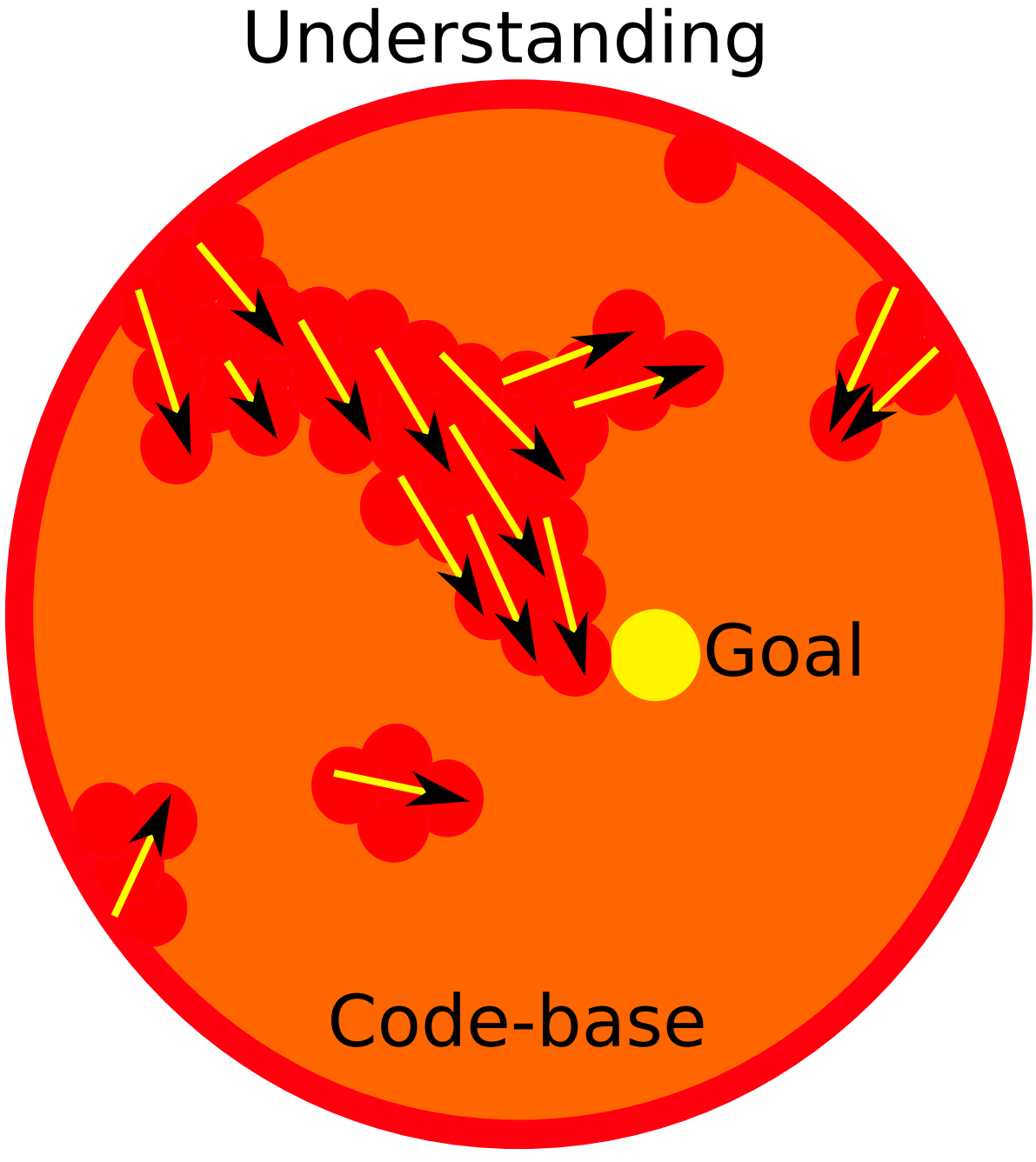
Hypothesis is both

- a sub-goal in understanding – direct code-observation
- a mapping: high-level concepts $\leftrightarrow$ code in front of you

$\text{hypothesis}_0 = f(\text{goal, behavior, design, surface questions})$
$\text{hypothesis}_n = f(\text{goal, behavior, design, hypothesis}_{n-1})$

Understanding Code: Hypothesis-guided



Hypothesis: Your Own Little Spanish Inquisition

Hypothesis are *abstraction for understanding code*

- write them down
- these are your current understanding of the code
- they abstract details of code into high-level statements
  - ...that humans can remember/understand
  - you *will* forget the code
  - you *should* forget the code

$\rightarrow$ *abstraction for reading code*

How do we confirm hypothesis?

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$\rightarrow$ *abstraction for reading code*

How do we confirm hypothesis?

- we don't
- we gain *confidence* in them
- they could go wrong at any point

In the Trenches, Looking at Code

I'm reading code, I have hypothesis and a goal...
...how do I direct my search through the code?

DFS? BFS?

In the Trenches, Looking at Code

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Onion model

- layers of abstraction
- layers of complexity
- important to distinguish between layers

Example

```
static inline void *
cbuf2buf(cbuf_t cb, int len)
{
        u32_t id;
        struct cbuf_meta *cm;
        union cbufm_info ci;
        void *ret = NULL;
        long cbidx;
        if (unlikely(!len)) return NULL;
        cbuf_unpack(cb, &id);

        CBUF_TAKE();
        cbidx = cbid_to_meta_idx(id);
again:
        do {
                cm = cbuf_vect_lookup_addr(cbidx);
                if (unlikely(!cm || cm->nfo.v == 0)) {
                        if (__cbuf_2buf_miss(id, len)) goto done;
                        goto again;
                }
        } while (unlikely(!cm->nfo.v));
        ci.v = cm->nfo.v;

        if (unlikely(!(cm->nfo.c.flags & CBUFM_TMEM))) goto done;
        if (unlikely(len > PAGE_SIZE)) goto done;
        ret = ((void*)(cm->nfo.c.ptr << PAGE_ORDER));
done:
        CBUF_RELEASE();
        assert(lock_contested(&cbuf_lock) != cos_get_thd_id());
        return ret;
}
```

Onion model: Everyone's Crying

Implication: When reading code, question

- is invoked function at same level
  ...or peeling off another layer?
- understand current level before next
  - get an intuition for current layer
  - confirm hypothesis about current layer
  - understand how next level is used
  - form hypothesis about next layer(s)
    - "that function must do x"
  - ROT: no hypothesis about fn? Don't go into it!
  - ROT: stay in the same file/source directory

The onion analogy – lots of weeping when peeling abstractions

- new peel, more crying $\rightarrow$ peel less!
- we're learning to peel underwater $\rightarrow$ peel better!

Brains have a Small Register File

Even within a peel, we have a problem:
...we suck at reading code

- Human short-term memory: $7 +/- 2$ items
  - each conditional (-1), loop (-1), variable (-1)
- CS = abstraction; use this!

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An onion peel:

- code contains more than 7 "things"
- at a given abstraction level *what can you instantly forget?*

Example: what to ignore?

```
static inline void *
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        CBUF_TAKE();
        cbidx = cbid_to_meta_idx(id);
again:
        do {
                cm = cbuf_vect_lookup_addr(cbidx);
                if (unlikely(!cm || cm->nfo.v == 0)) {
                        if (__cbuf_2buf_miss(id, len)) goto done;
                        goto again;
                }
        } while (unlikely(!cm->nfo.v));
        ci.v = cm->nfo.v;

        if (unlikely(!(cm->nfo.c.flags & CBUFM_TMEM))) goto done;
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Example: what to ignore?

```
cbuf2buf(struct cbuf cb, int len)
{
        u32_t id;
        struct cbuf_meta *cm;
        union cbufm_info ci;
        long cbidx;
        if (len) {
                int again;

                cbuf_unpack(&cb, &id);

                CBUF_TAKE();
                cbidx = cbid_to_meta_idx(id);
                do {
                        again = 0;
                        cm = cbuf_lookup_addr(cbidx);
                        if (!cm || cm->nfo.v == 0) {
                                if (cbuf_2buf_get(id, len)) {
                                        CBUF_RELEASE();
                                        return NULL
                                }
                                again = 1;
                        }
                } while (again || !cm->nfo.v);
                ci.v = cm->nfo.v;

                if ((cm->nfo.c.flags & CBUFM_TMEM)) {
                        if (len <= PAGE_SIZE) {
                                CBUF_RELEASE();
                                return ((void*)
                                        (cm->nfo.c.ptr << PAGE_ORDER));
                        }
                }
                CBUF_RELEASE();
                return NULL;
        }
        return NULL;
```

Small register file? Be *Actively* Lazy

- What can I *choose* to ignore?
  - error cases – how discriminate these conditions?
  - edge cases – what's an edge case?
  - variables – until used in an important context
  - loops – distill to one operation
- largest "productivity" boost in reading
  - *hypothesis should enable these simplifications*
- goal: code details $\rightarrow$ hypothesis
  - remember hypothesis, not details
- Note: very little of this applies to *algorithms*

Hypothesis vs. Code: DEATHMATCH

Relationship between code and hypothesis

- Hypothesis about code $\rightarrow$ interpretation of code
- Interpretation of code $\rightarrow$ confirm/refute hypothesis

Important relationship to understand

- "understanding" code is
  - making stronger, higher-level, confirmed hypothesis
  - enables a deeper investigation of code
  - *"virtuous cycle"*

Hypothesis vs. Code: DEATHMATCH

$$\text{hypothesis}_0 = f(\text{goal, behavior, design, surface questions})$$
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$$\text{understanding} = \{\text{hypothesis}_m \mid \text{m} \leq \text{sufficiently large } n\}$$

The Algorithm

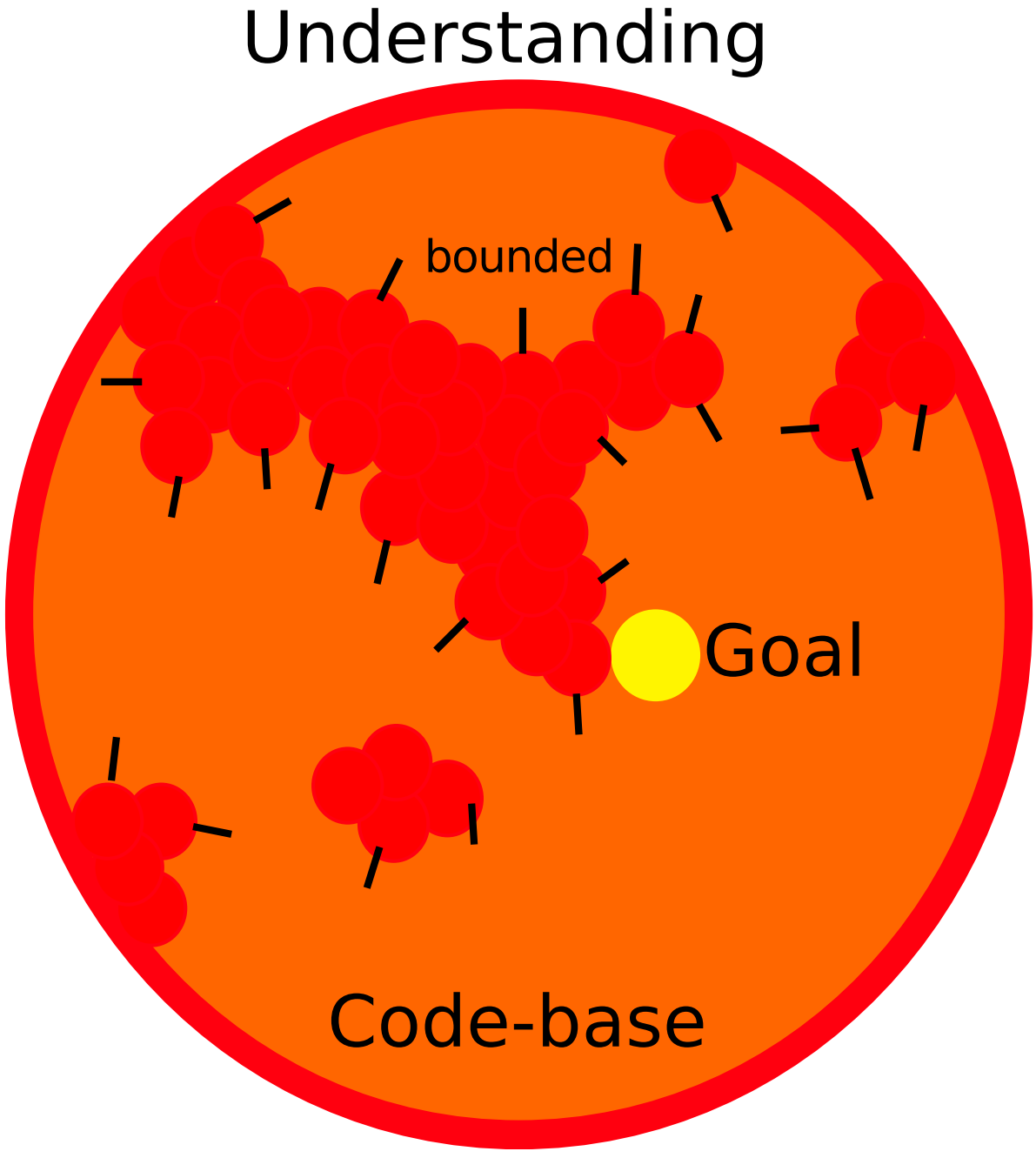
Branch and (aggressively) Bound

- Peel-First Search (PFS) through code
- aggressively ignore branch possibilities (bound)
  - error/edge cases, defined by current hypothesis
  - deeper levels of abstraction than currently useful
- refine, confirm, and synthesize hypothesis

Whole purpose: *actively engage* in code-understanding

- large difference between reading & understanding a book

Understanding Code: Bounded, PFS



Naming

Want your code to be impossible to understand?

One simple, easy step!!!

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Choose your names badly

- best cue that a branch is unimportant
- best hypothesis formation tool

bad naming = intractable code

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Spend (lots of) time thinking about naming

ROT: don't write code if you don't value naming

The Good News

This is *a lot* easier with practice

- refine, customize your PFS and hypothesis formation
- the more you read, the easier it is to do so
- ...even in *other* code-bases

The virtuous cycle is exponential

- faster formation/confirmation of hypothesis
  $\rightarrow$ faster code interpretation
- faster code interpretation
  $\rightarrow$ faster formation/confirmation of hypothesis

Anecdote: priority-aware IPIs in Linux

The Dose of Reality

"reading" code is not enough

- "how you do'in" – skimming code,
  $\rightarrow$ *will never lead to system understanding*
- looking at swimsuit models – only reading papers,
  $\rightarrow$ *will never lead to system understanding*

Only via active engagement in

- *goal- and hypothesis-driven*
- *structured code search*

Implications

You **can not** *write good code*
until you understand how to *read code*

- no sane system optimizes for writing code (`perl` aside)
- optimize for reading code

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System style and conventions are important

- rules for hypothesis formation
  - What are `i`, `j`, and `k`???
- see COMPOSITE style guide

> `daemon(` When you learn to understand code, how can you write it to ease the process? `)`

Implications II

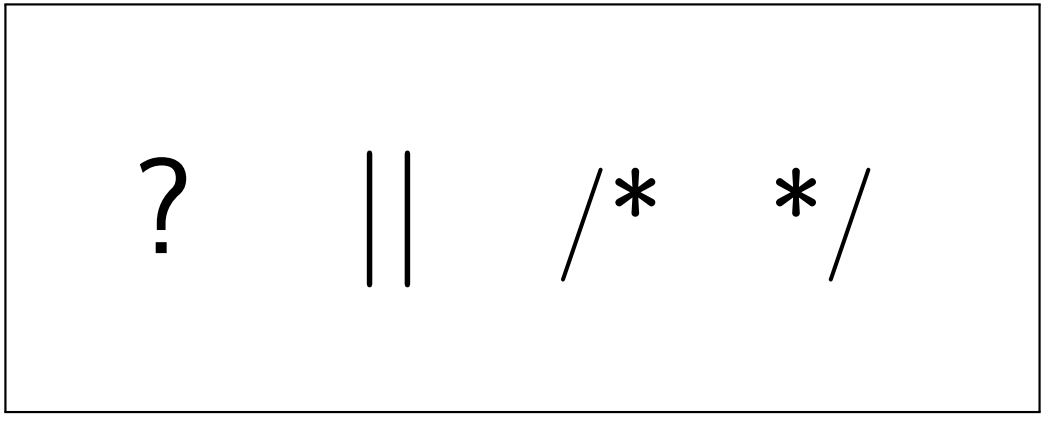
This doesn't mean code will be optimally readable

- readable code $\rightarrow\leftarrow$ optimization
  ...only optimize when necessary
- readable code $\rightarrow\leftarrow$ generic code
  ...don't over-generalize

taste in code construction

- benevolent dictator better have it

Thank You!



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