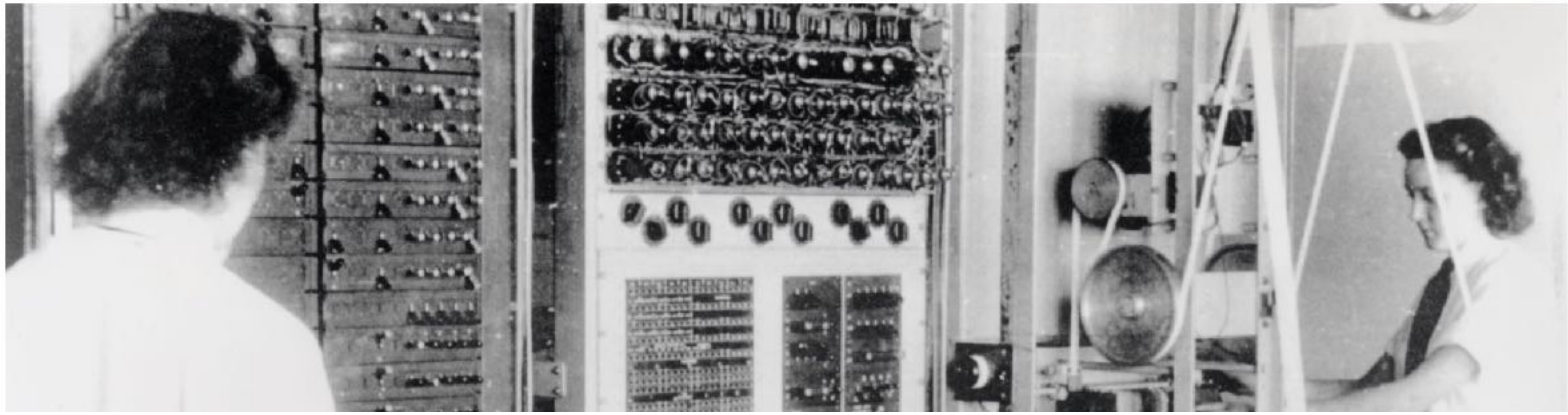
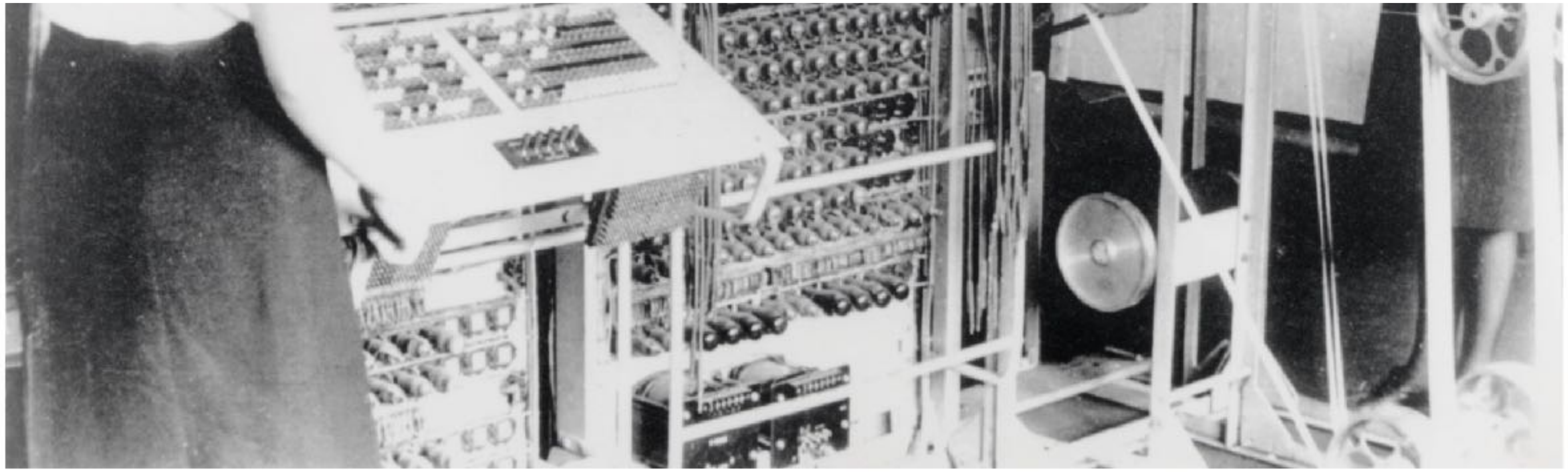
Harvard John A. Paulson
School of Engineering
and Applied Sciences

PL/HCI Seminar (252R/279R)

MW 12-1:15 PM in ~~LISE 303~~ Pierce 209



Making communicating with computers more accessible: easier, faster, and safer



Welcome!

- This is a graduate course; undergrads are welcome.
  - can have taken 152 *or* 179 and be just fine, not necessarily both
- You (as a student presenter) will present and lead discussion for at least one paper
- You (as a non-presenting student) will post questions and a summary of the design arguments by Friday of the previous week
- Key learning outcomes:
  - (279r) to look at scientific publications, identify the core design arguments, write new design arguments, and evaluate them
  - (252r) understand, design and implement language abstractions for solving a task
- Group projects will be composed of both “HCI folks” and “PL folks”

Welcome!

- In undergraduate courses, you **consume knowledge** and practice applying it.
- In graduate courses like this one, you attempt to **generate new knowledge.**

I’m an HCI person.

I build novel interfaces and evaluate them in studies.

Since ~2015, I have found **PL technology** useful
for providing the *magic* behind the screen.

Evaluation is Hard.

But also, evaluation *with respect to what?*

Outline

1. **Design Arguments**
2. Some HCI evaluation techniques
3. Means of communicating with computers

Design Arguments

Evidence

How do you know?

Need

Need Thesis

Stakeholders + Domain Person **P** [in setting **S**]

Core tension wants to achieve goal **G** but obstacles $\mathbf{O}_{1\text{-}N}$ get in the way.

Evidence

How do existing approaches fail?

Any solution also has to:
satisfy constraints $\mathbf{X}_{1\text{-}N}$,
minimize costs $\mathbf{Y}_{1\text{-}N}$,
and avoid obstacles $\mathbf{Z}_{1\text{-}N}$.

Axioms As designers, we bring the following principles and constraints $\mathbf{A}_{1\text{-}N}$.

Evidence

What characteristics have you borrowed from solutions that succeeded in analogous settings?

What differentiates your approach from previous solutions that failed?

How have stakeholders responded to/been able to use your approach?

Approach Thesis

Our approach, _____________,
has characteristics $\mathbf{C}_{1\text{-}N}$
that help stakeholders achieve their goal **G** while avoiding obstacles $\mathbf{O}_{1\text{-}N}$

Visualizing API Usage Examples at Scale

Elena L. Glassman‡*, Tianyi Zhang‖*, Björn Hartmann‡, Miryung Kim‖
‡*UC Berkeley, Berkeley, CA, USA
‖*UC Los Angeles, Los Angeles, CA, USA
{eglassman, bjoern}@berkeley.edu, {tianyi.zhang, miryung}@cs.ucla.edu

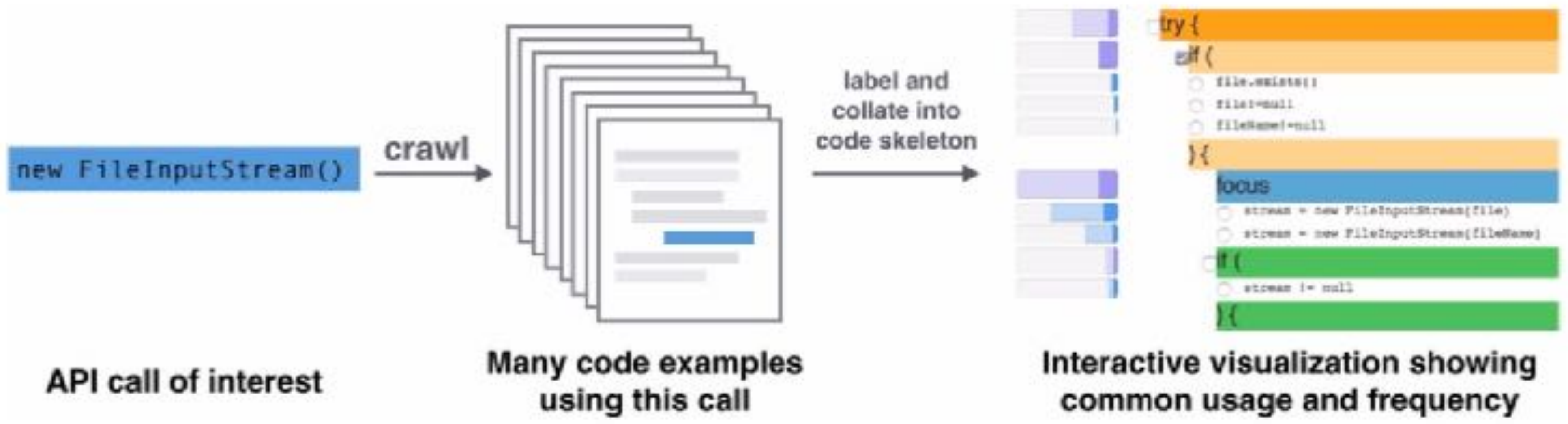


Figure 1. EXAMPLORE **takes a focal API call that a programmer is interested in, locates uses of that API call in a large corpus of mined code examples, and then produces an interactive visualization that lets programmers explore common usage patterns of that API across the corpus.**

ABSTRACT

Using existing APIs properly is a key challenge in programming, given that libraries and APIs are increasing in number and complexity. Programmers often search for online code examples in Q&A forums and read tutorials and blog posts to learn how to use a given API. However, there are often a massive number of related code examples and it is difficult for a user to understand the commonalities and variances among them, while being able to drill down to concrete details. We introduce an interactive visualization for exploring a large collection of code examples mined from open-source repositories at scale. This visualization summarizes hundreds of code examples in one synthetic code skeleton with statistical distributions for canonicalized statements and structures enclosing an API call. We implemented this interactive visualization for a set of Java APIs and found that, in a lab study, it helped users (1) answer significantly more API usage questions correctly and comprehensively and (2) explore how other programmers have used an unfamiliar API.

INTRODUCTION

Learning how to correctly and effectively use existing APIs is a common task — and a core challenge — in software development. It spans all expertise levels from novices to professional software engineers, and all project types from prototypes to production code. The landscape of publicly available APIs is massive and constantly changing, as new APIs are created in response to shifting programmer needs. Within companies, the same is true, perhaps even more so: joining a company can require learning a whole new set of proprietary APIs before a developer becomes an effective contributor to the company codebase. Developers often are stymied by various learning barriers, including overly specific or overly general explanations of API usage, lack of understanding about the interaction between multiple APIs, lack of alternative uses, and difficulty identifying program statements and structures related to an API [11, 19, 5].

One study found that the greatest obstacle to learning an API is "*insufficient or inadequate examples.*" [19] Official documenta-

Figure 1. EXAMPLORE **takes a focal API call that a programmer is interested in, locates uses of that API call in a**
and then produces an interactive visualization that lets programmers explore common usage patterns of that API

ABSTRACT

Using existing APIs properly is a key challenge in programming, given that libraries and APIs are increasing in number and complexity. Programmers often search for online code examples in Q&A forums and read tutorials and blog posts to learn how to use a given API. However, there are often a massive number of related code examples and it is difficult for a user to understand the commonalities and variances among them, while being able to drill down to concrete details. We introduce an interactive visualization for exploring a large collection of code examples mined from open-source repositories at scale. This visualization summarizes hundreds of code examples in one synthetic code skeleton with statistical distributions for canonicalized statements and structures enclosing an API call. We implemented this interactive visualization for a set of Java APIs and found that, in a lab study, it helped users (1) answer significantly more API usage questions correctly and comprehensively and (2) explore how other programmers have used an unfamiliar API.

INTRODUCTION

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Outline

1. Design Arguments
2. **Some HCI formative design and evaluation techniques**
3. Means of communicating with computers

Some HCI Formative Design Techniques

- Survey
- Interview
- Contextual inquiry
  - Observation in context
  - Requests for explanation
- Wizard of Oz
- Technology probe

Some HCI Evaluation Techniques

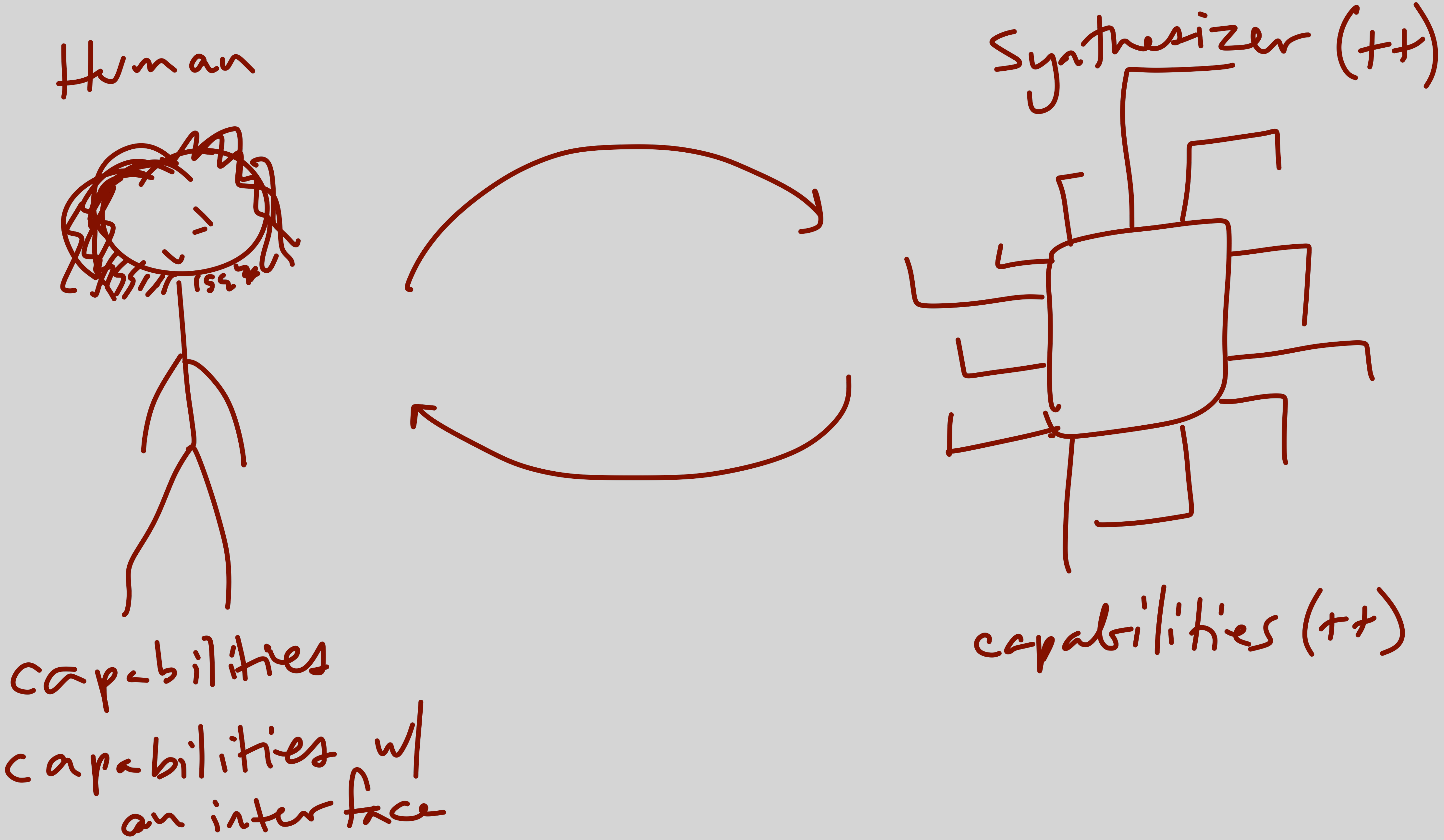
- User study
  - Task design
  - Metrics
- Deployment
- Interview or survey of deployment participants
- Crowdsourcing, i.e., Amazon Mechanical Turk

Outline

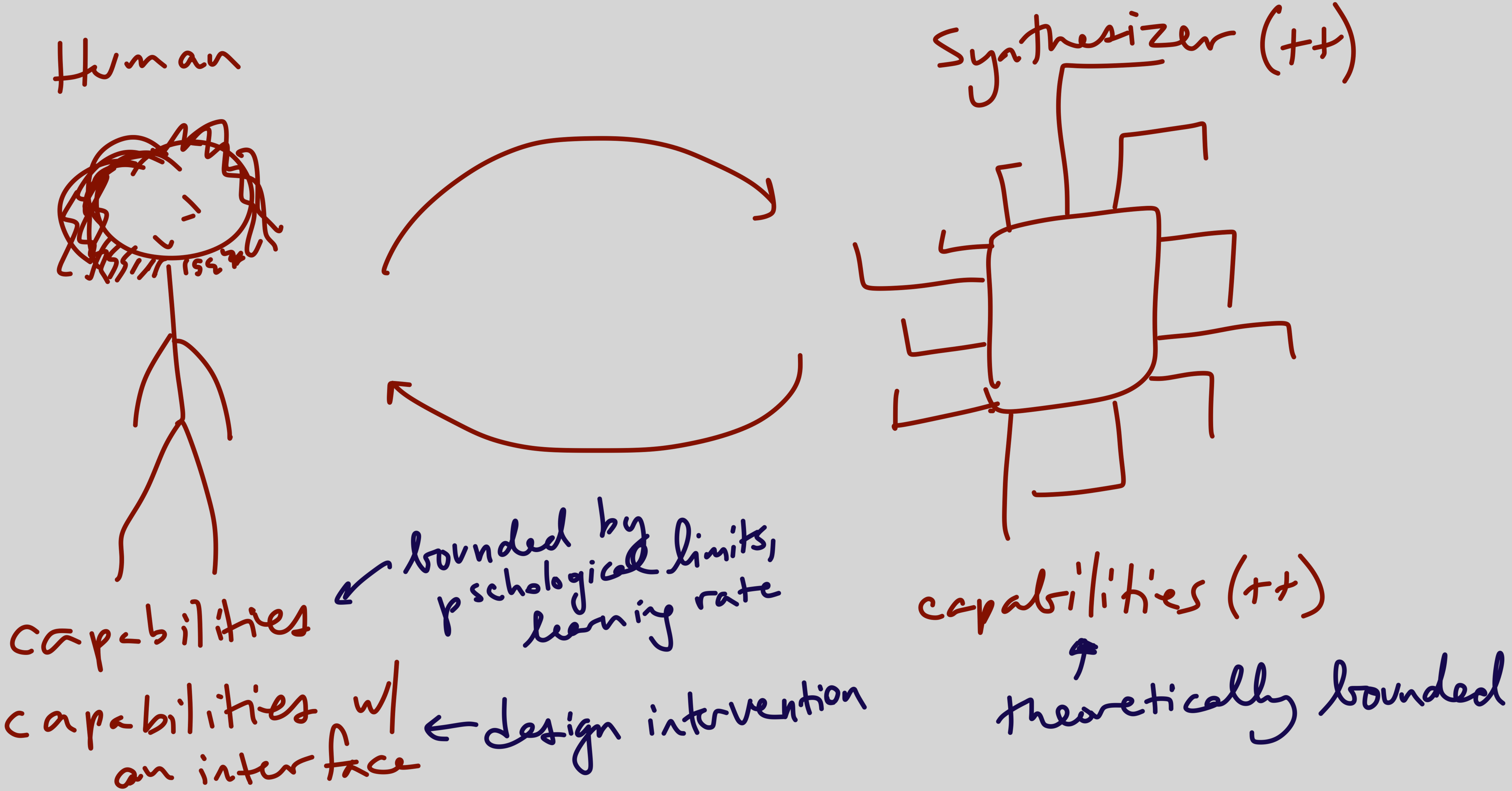
1. Design Arguments
2. Some HCI formative design and evaluation techniques
3. **Means of communicating with computers**

Communicating with Computers

- Human intent
  - Examples
  - Statement(s) in a programming language
  - Natural language
  - …
- Computer’s interpretation
  - Program
  - Behavior
    - Action in response to a human request
    - Results of running understood program on additional data


Human
capabilities
capabilities w/ an interface
Synthesizer (++)
capabilities (++)

Approach



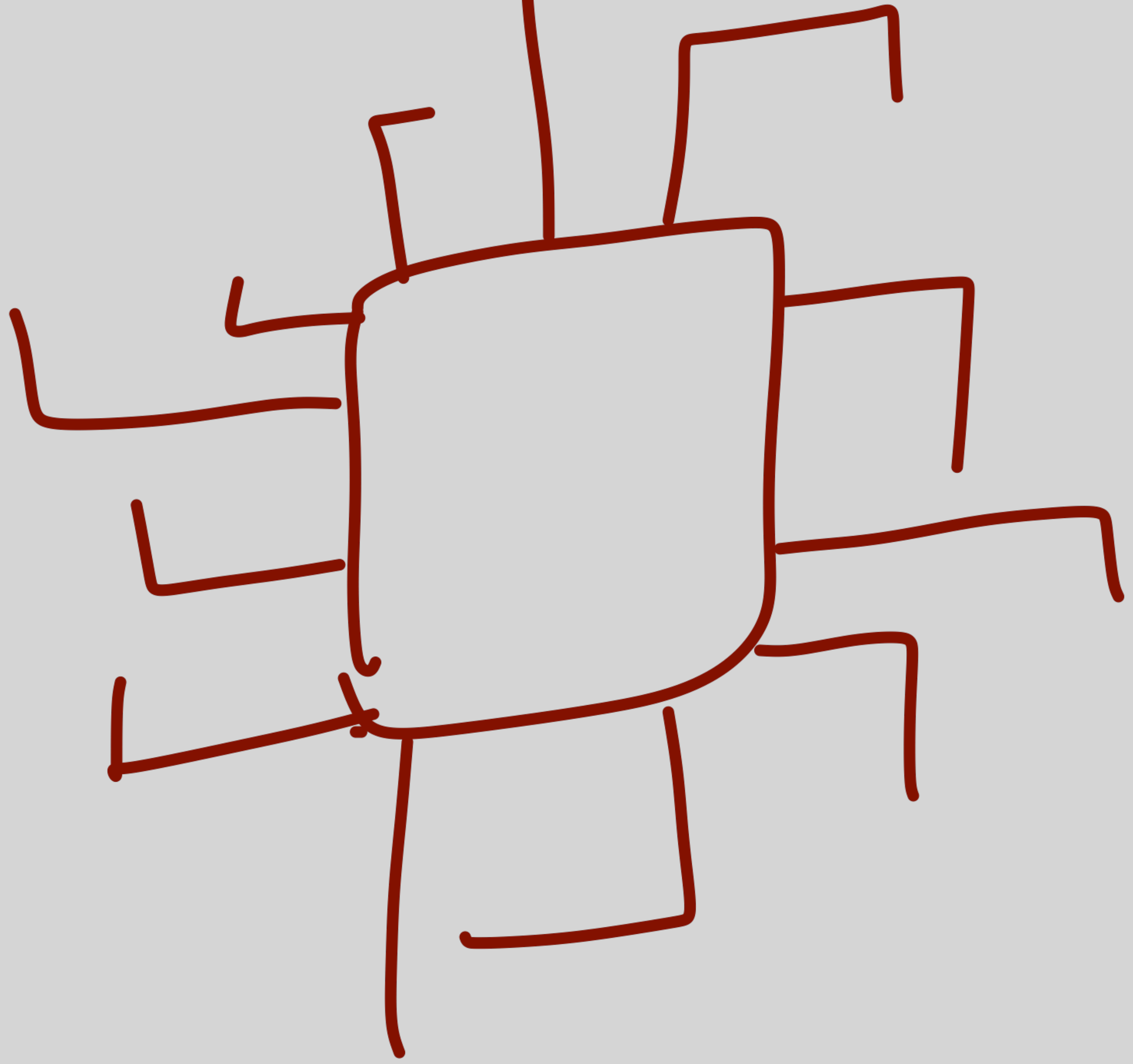
Human
Synthesizer (++)
capabilities
bounded by pschological limits, learning rate
capabilities w/ an interface
design intervention
capabilities (++)
theoretically bounded

Approach

Human

programming lang
natural lang
examples
specifications
serving as an oracle

Synthesizer (++)

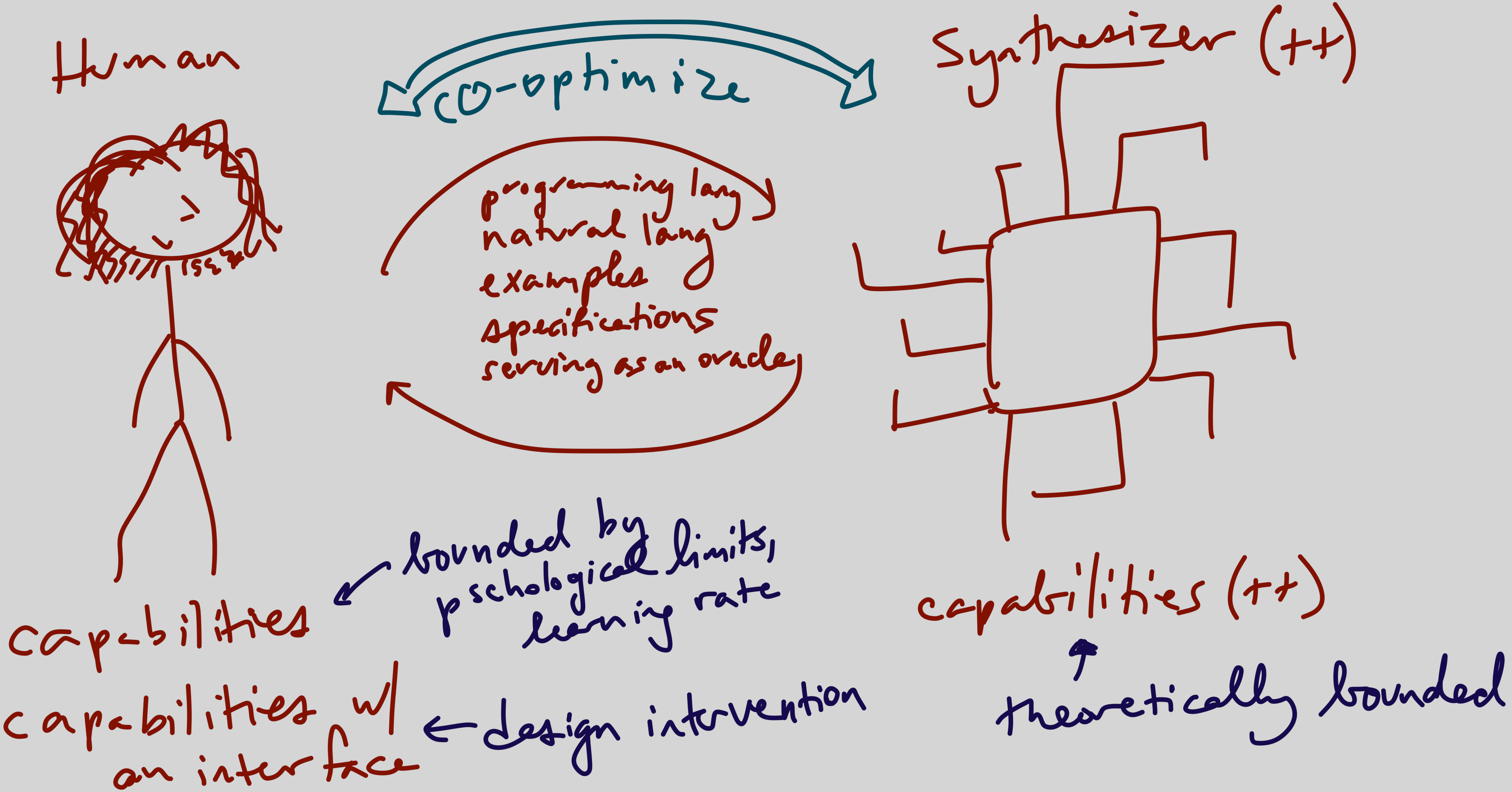


capabilities ← bounded by pschological limits, learning rate

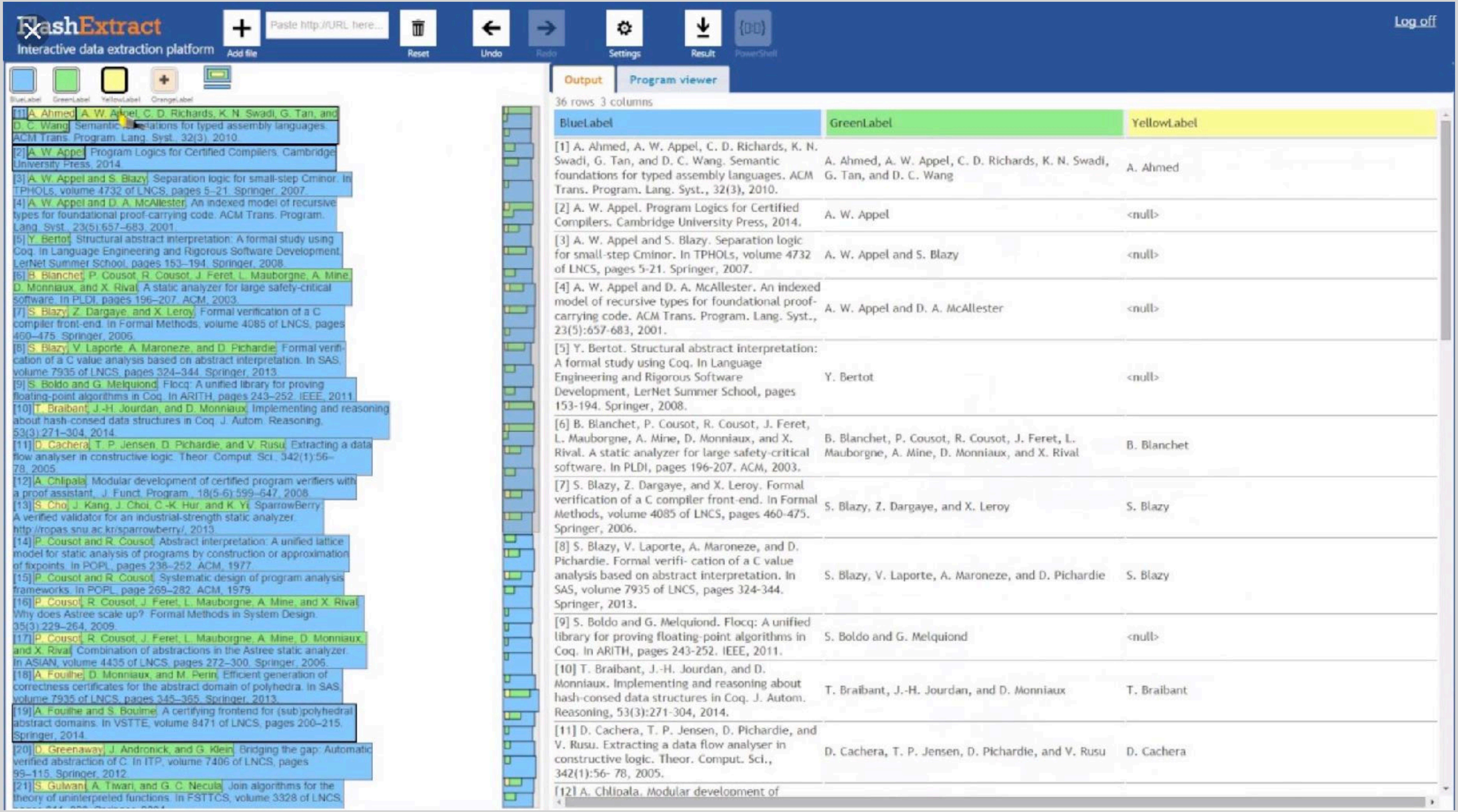
capabilities w/ an interface ← design intervention

capabilities (++) ↑ theoretically bounded

Approach



Human
co-optimize
Synthesizer (++)
programming lang
natural lang
examples
specifications
serving as an oracle
bounded by pschological limits, learning rate
capabilities
capabilities w/ an interface
design intervention
capabilities (++)
theoretically bounded


FlashExtract
Interactive data extraction platform
Add file
Paste http://URL here...
Reset
Undo
Redo
Settings
Result
PowerShell
Log off
BlueLabel
GreenLabel
YellowLabel
OrangeLabel
Output
Program viewer
36 rows 3 columns
BlueLabel
GreenLabel
YellowLabel
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A. Ahmed, A. W. Appel, C. D. Richards, K. N. Swadi, G. Tan, and D. C. Wang
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[2] A. W. Appel. Program Logics for Certified Compilers. Cambridge University Press, 2014.
A. W. Appel
<null>
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Y. Bertot
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D. Cachera, T. P. Jensen, D. Pichardie, and V. Rusu
D. Cachera
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PROSE Architecture

Credit: Alex Polozov

“FlashFill in Excel is designed to cater to users that care not about the program but about its behavior on the small number of input rows in the spreadsheet.

Such users can simply eye-ball the outputs of the synthesized program and provide another example if they are incorrect.

However, this becomes much more cumbersome (or impossible) with a larger spreadsheet.”

	A	B	C
1	First Name	Last Name	Full Name
2	Jay	Shasthri	Jay Shasthri
3	Pratap	Pillai	Pratap Pillai
4	Madhu	Srivastava	Madhu Srivastava
5	Victoria	Marsh	Victoria Marsh
6	David	Pizarro	David Pizarro

`support.office.com`

- Lu et al. “Interactive Program Synthesis” (2017)

"We have observed that inspecting the synthesized program directly also does not establish enough confidence in it even if the user knows programming.

Two main reasons for this are
(i) program readability, and
(ii) *the users' uncertainty in the desired intent due to hypothetical unseen corner cases in the data."*

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Discussion Preview

What is particularly hard about evaluating methods for communicating with computers?

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Evaluation

Why is it hard:
some puzzlers from programming languages

puzzler 1

easy vs safe

?

Array<Cat>

<:

Array<Animal>

puzzler 2

semantics

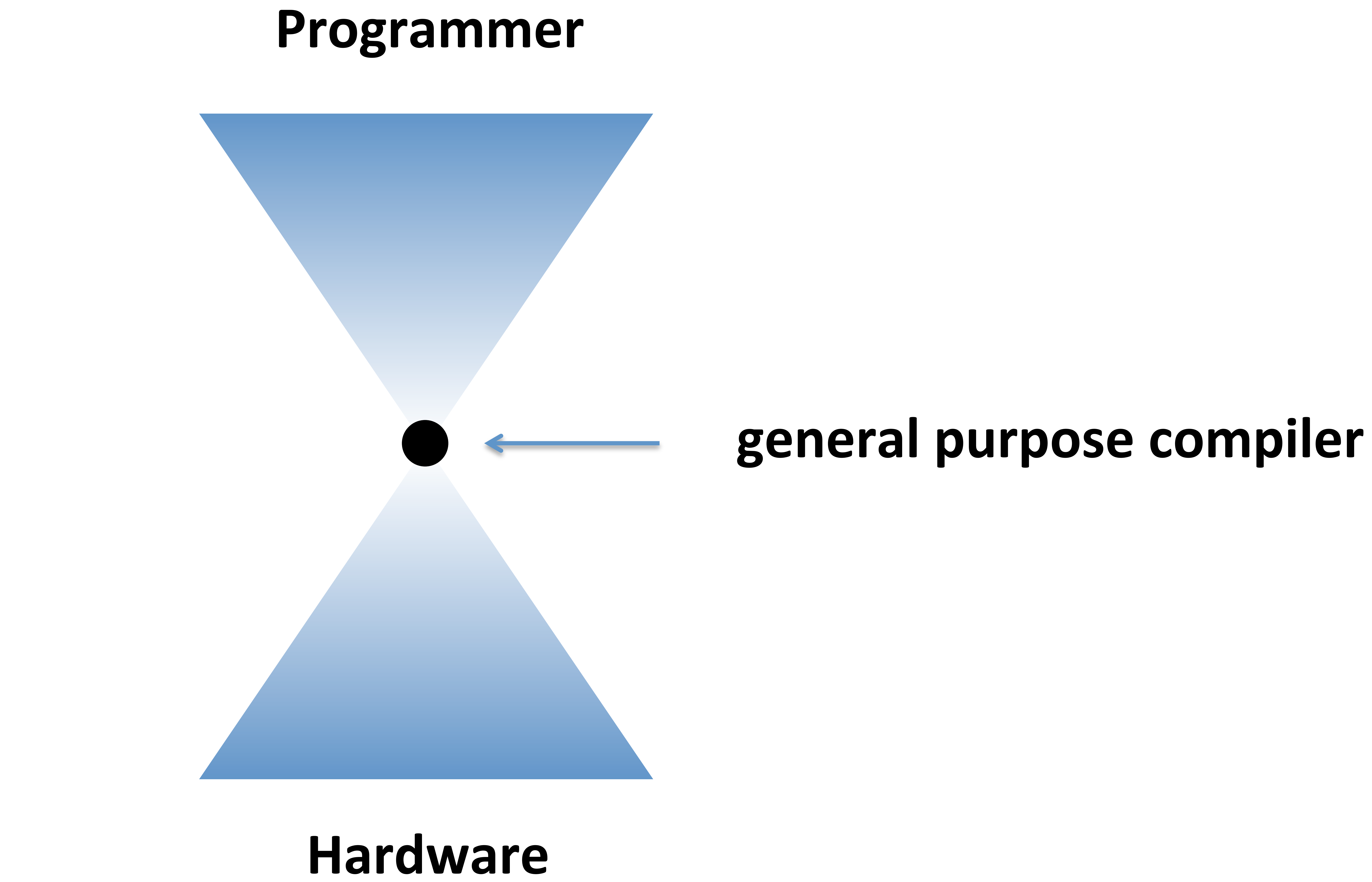
?

- ```
  let x = 1 in
  let f = let x = 2 in (\y -> y+x)
  let x = 3 in
  f 0
  ```

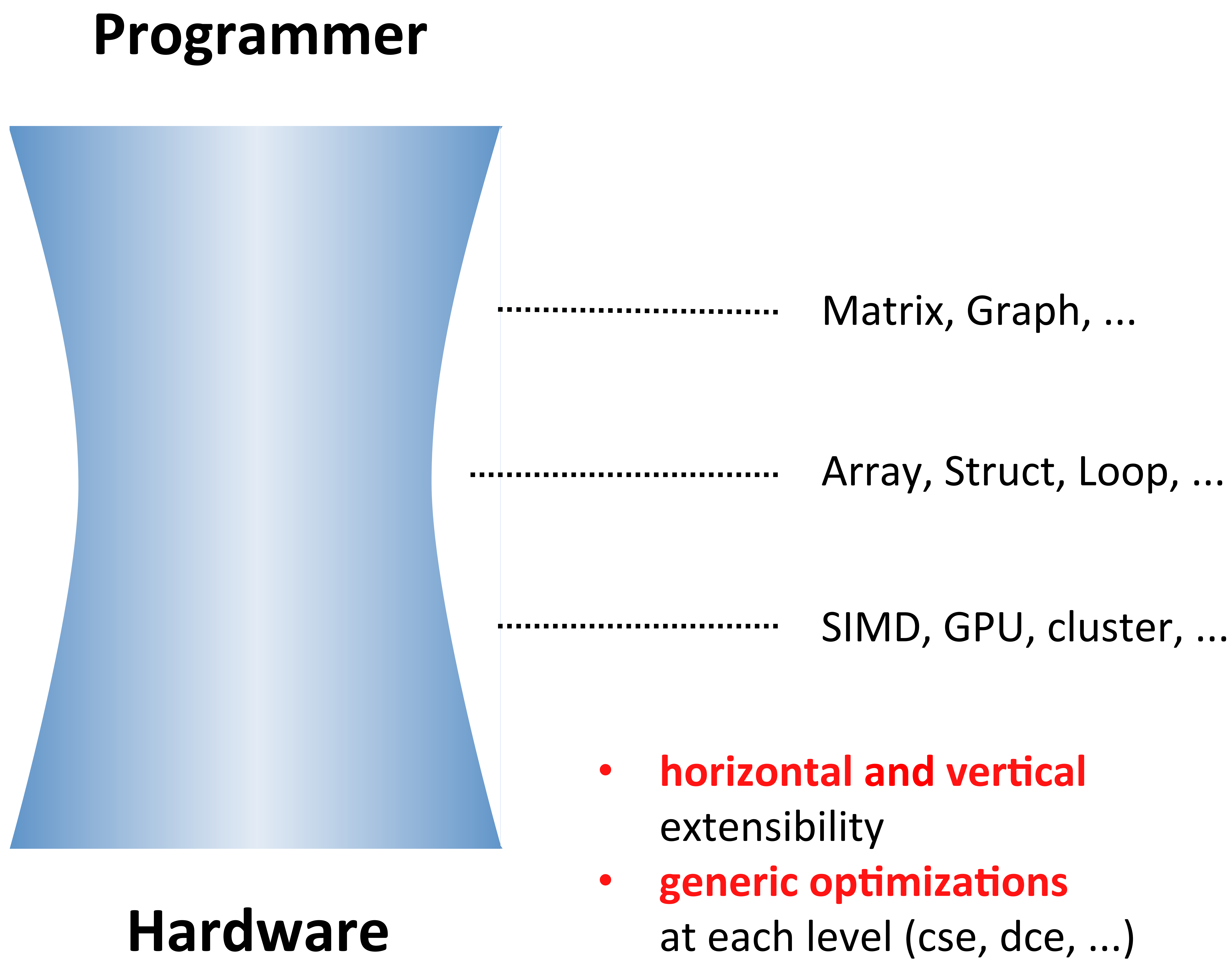
- Is the result 1, 2 or 3?
  ```

puzzler 3

cognitive overhead



(illustration: Markus Püschel)



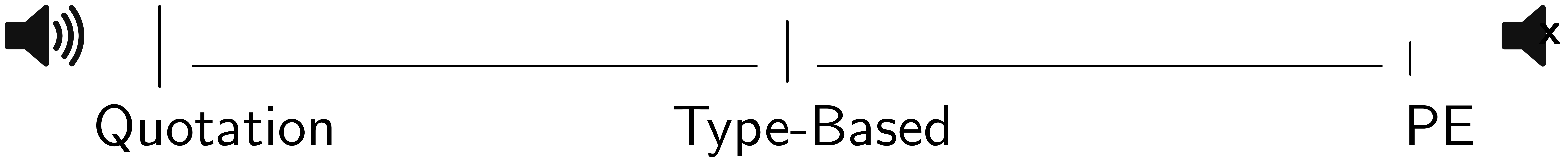
- **horizontal and vertical** extensibility
- **generic optimizations** at each level (cse, dce, ...)

Staging?

- multi-level language
  n | x | e $@^b$ e | λ^bx.e | ...
- MetaML / MetaOCaml
  n | x | e e | λx.e | <e> | ~e | run e
- Lightweight Modular Staging (LMS) in Scala
  driven by types: T vs Rep[T]

“People confuse the familiar for the simple. For new features, people insist on LOUD explicit syntax. For established features, people want terse notation.”

—Bjarne Stroustrup



Power in Scala

```
def square(x: Int): Int = x*x

def power(b: Int, n: Int): Int =
  if (n == 0) 1
  else if (n % 2 == 0) square(power(b, n/2))
  else b * power(b, n-1)

// power(2, 7) == 128
```

Staged Power in Scala/LMS

```
def square(x: Rep[Int]): Rep[Int] = x*x

def power(b: Rep[Int], n: Int): Rep[Int] =
  if (n == 0) 1
  else if (n % 2 == 0) square(power(b, n/2))
  else b * power(b, n-1)

def snippet(b: Rep[Int]) = power(b, 7)
```

Generated Power n=7

```
class Snippet extends ((Int)=>(Int)) {
  def apply(x0:Int): Int = {
    val x1 = x0 * x0
    val x2 = x0 * x1
    val x3 = x2 * x2
    val x4 = x0 * x3
    x4
  }
}
```

Power in OCaml

```
let square x = x * x

let rec power n x =
    if n = 0 then 1
    else if n mod 2 = 0 then square (power (n/2) x)
    else x * (power (n-1) x)

(* val power : int -> int -> int = <fun> *)
```

Staged Power in MetaOCaml

```
let square x = x * x

let rec spower n x =

  if n = 0 then .<1>.

  else if n mod 2 = 0 then .<square .~(spower (n/2) x)>.

  else .<.~x * .~(spower (n-1) x)>.

(* val spower : int -> int code -> int code = <fun> *)
```

Generated Code

```
let spower7_code = .<fun x -> .~(spower 7 .<x>.)>.;;

(*

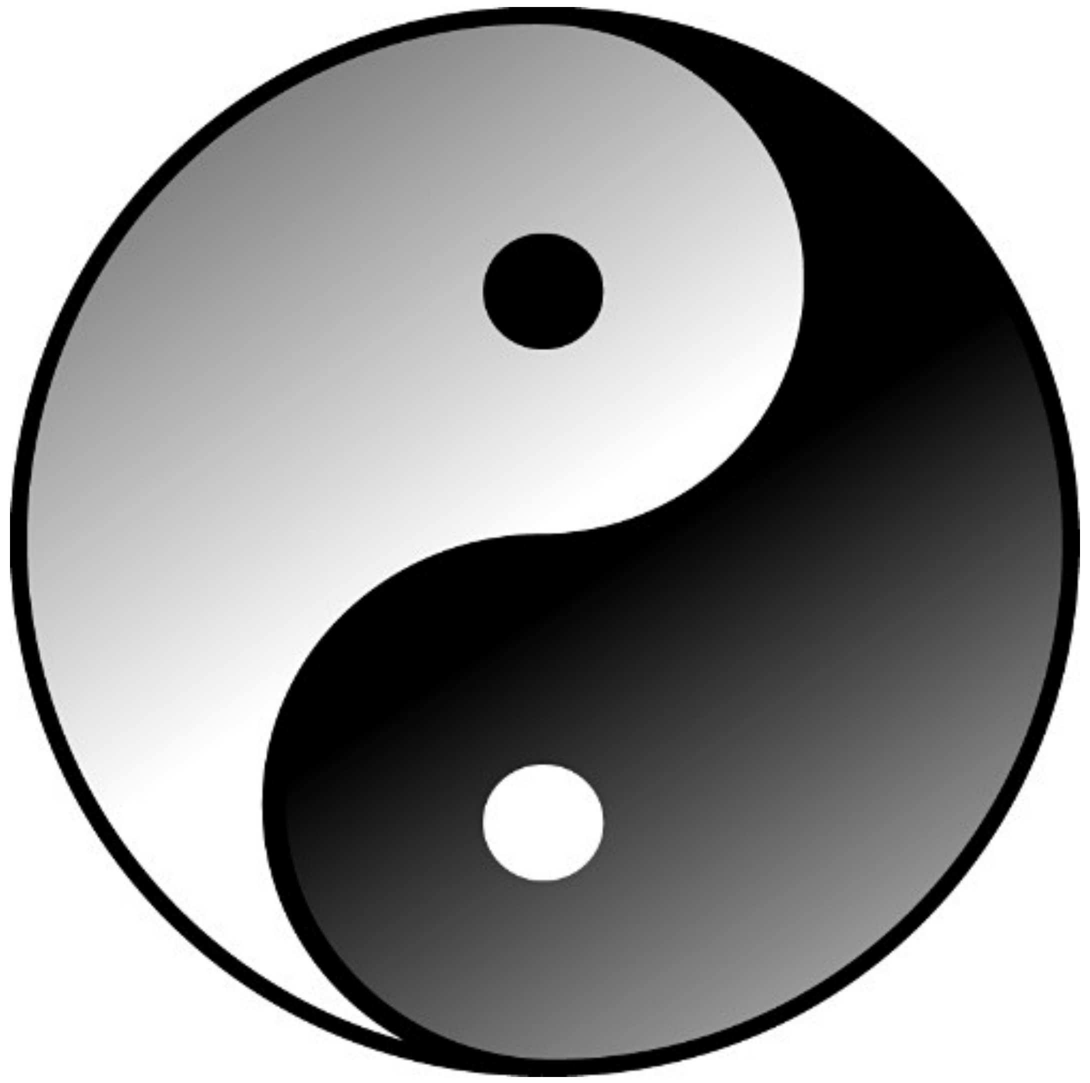
val spower7_code : (int -> int) code = .<

  fun x_1 ->

    x_1 * ((* CSP square *) (x_1 *
          ((* CSP square *) (x_1 * 1))))>.

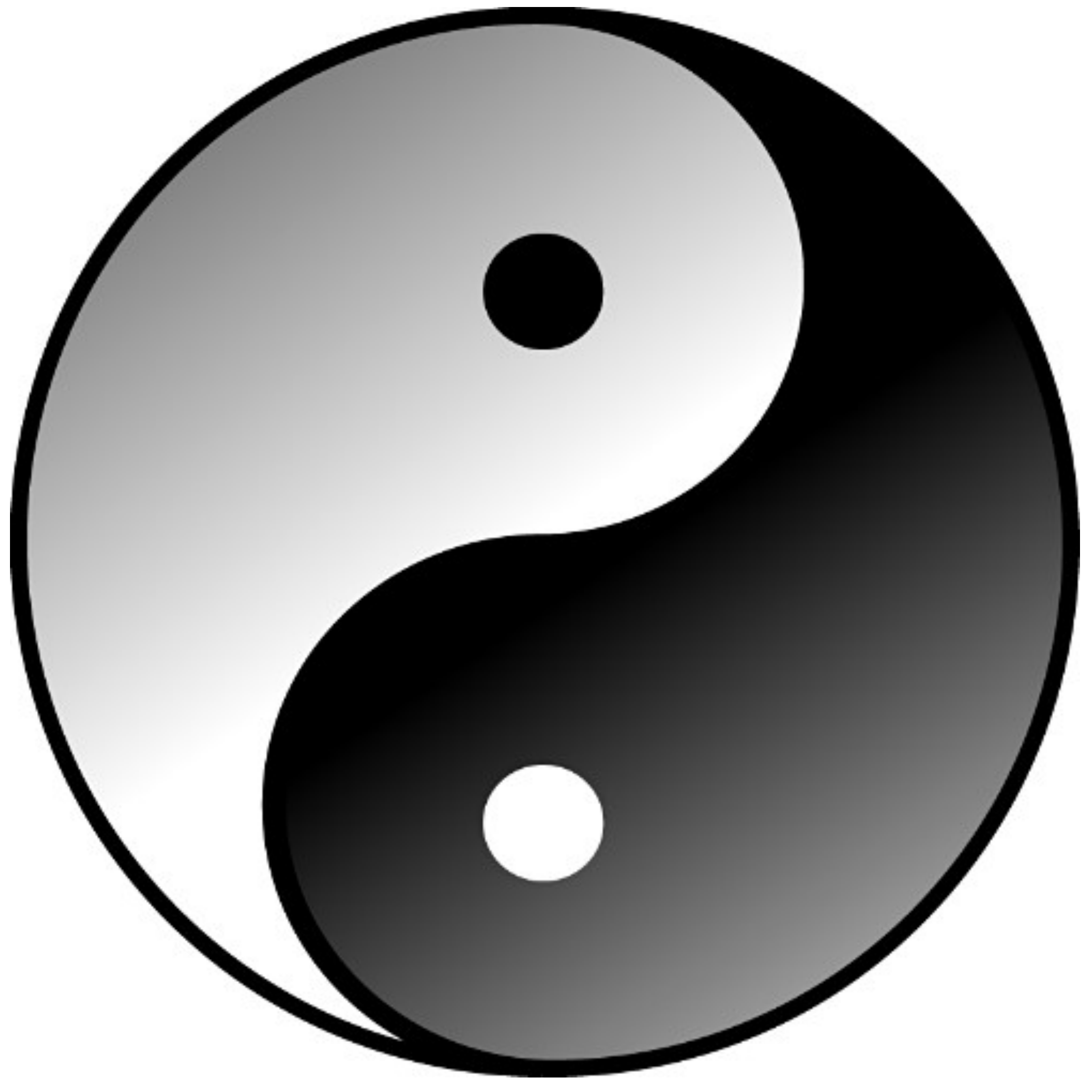
*)
```

Program generically…



… and run specialized!

Program generically…
(save human time)



… and run specialized!
(save computer time)

A matrix vector product, where the matrix is known (static) but the vector is unknown (dynamic),

e.g., for a Hidden Markov Model (HMM) where a single transition matrix is multiplied by many different observation vectors.

–Shonan Challenge for Generative Programming (PEPM'13)

Unstaged

```
def matrix_vector_prod(a: Array[Array[Int]],
                       v: Array[Int]) = {
  val n = a.length
  val v1 = new Array[Int](n)
  for (i <- (0 until n)) {
    for (j <- (0 until n)) {
      v1(i) = v1(i) + a(i)(j) * v(j)
    }
  }
  v1
}
```

Shonan Challenge

```
def matrix_vector_prod(a0: Array[Array[Int]],
                        v: Rep[Array[Int]]) = {
  val n = a0.length
  val a = staticData(a0)
  val v1 = NewArray[Int](n)
  for (i <- (0 until n):Range) {
    val sparse = a0(i).count(_ != 0) < 3
    for (j <- unrollIf(sparse, 0 until n)) {
      v1(i) = v1(i) + a(i).apply(j) * v(j)
    }
  }
  v1
}
```

Shonan Challenge

```
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    for (j <- unrollIf(sparse, 0 until n)) {
      v1(i) = v1(i) + a(i).apply(j) * v(j)
    }
  }
  v1
}
```

Example Matrix

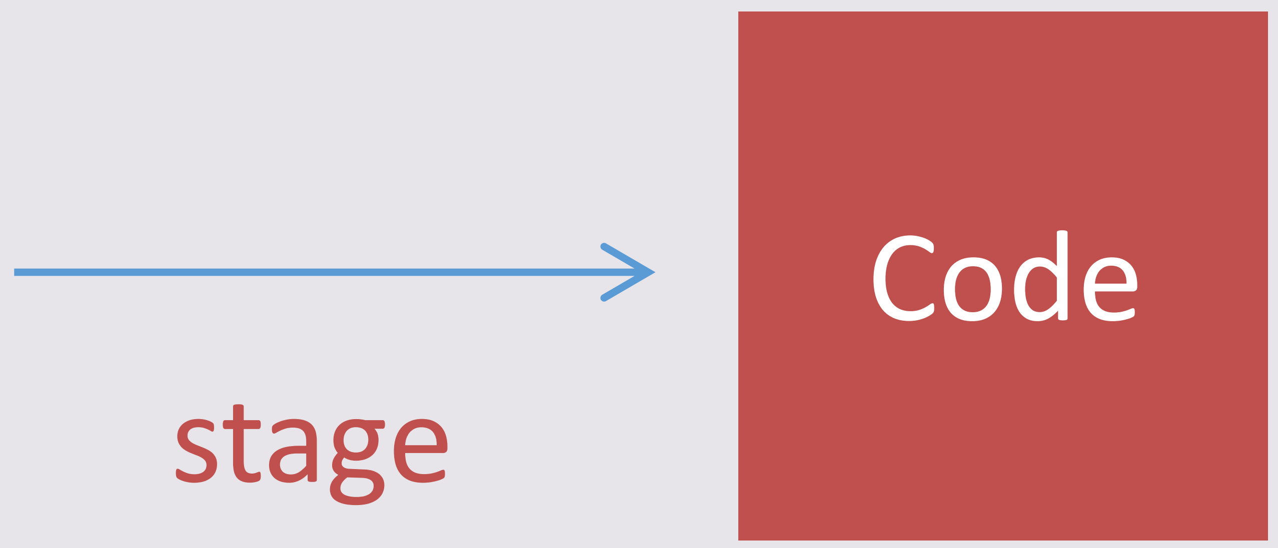
```
val a0 =
  A(A(1, 1, 1, 1, 1), // dense
    A(0, 0, 0, 0, 0), // null
    A(0, 0, 1, 0, 0), // sparse
    A(0, 0, 0, 0, 0),
    A(0, 0, 1, 0, 1))
```

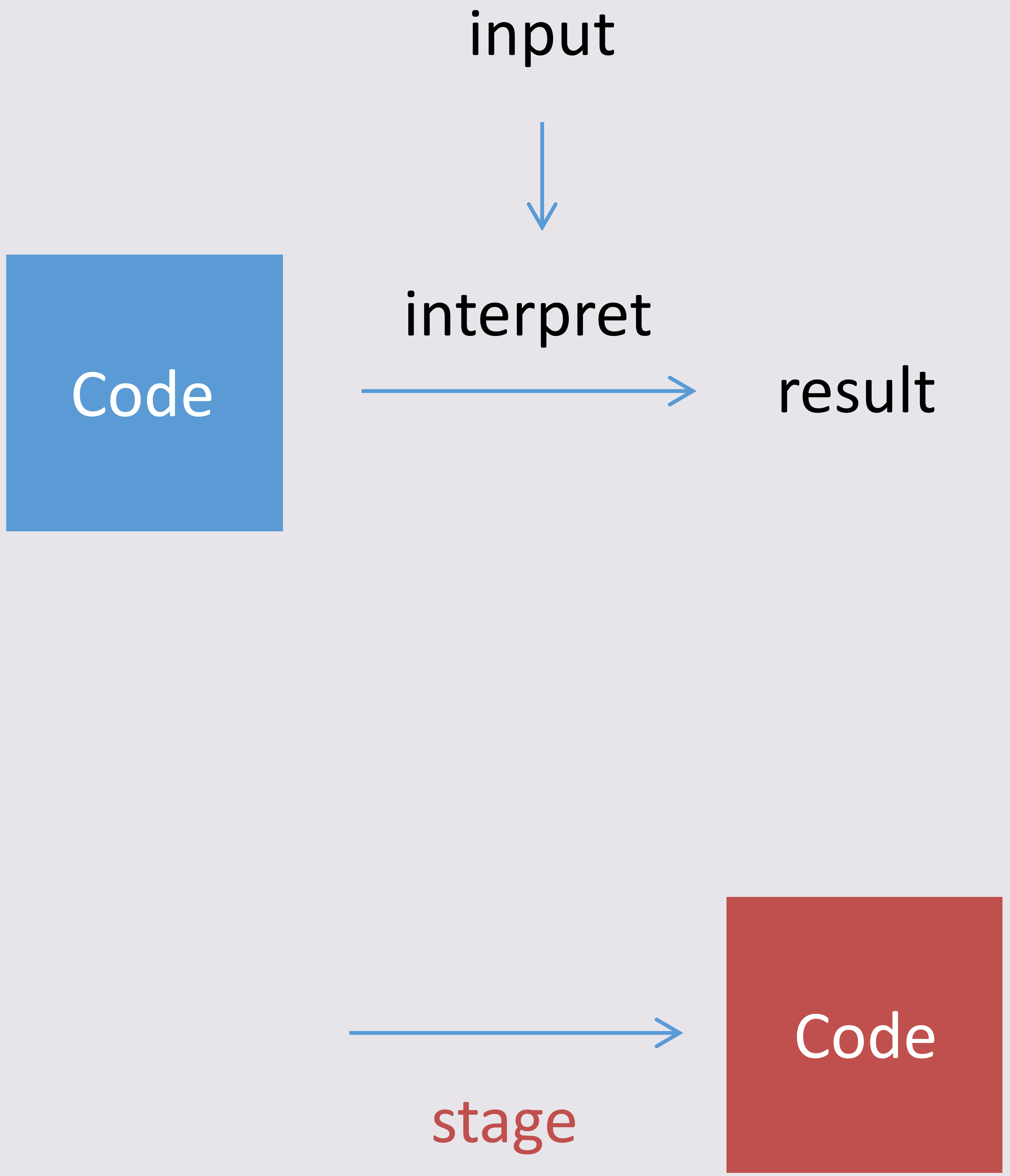
Generated Code

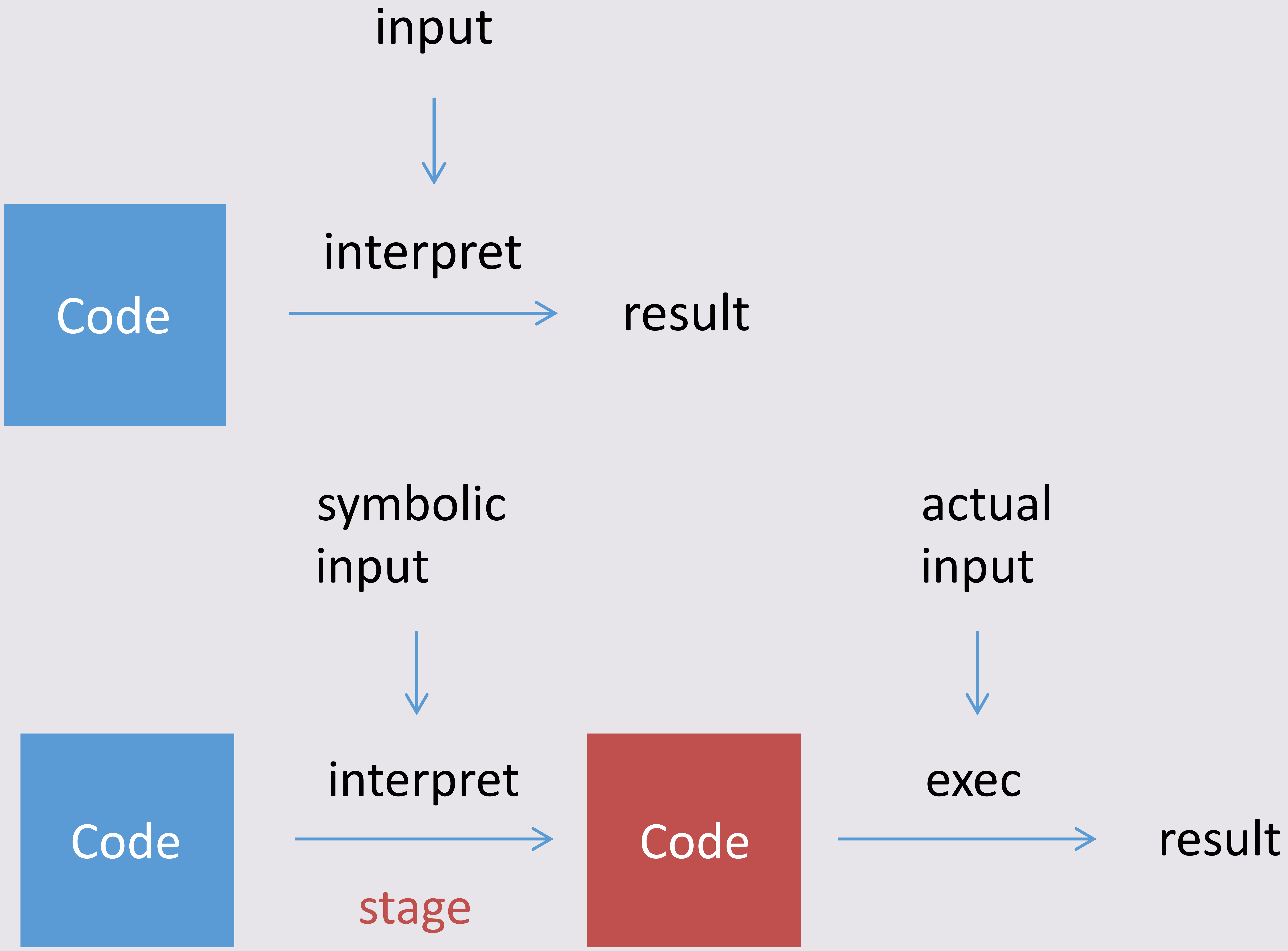
```
class Snippet(px6:Array[Int]) extends ((Array[Int])=>(Array[Int])) {
  def apply(x0:Array[Int]): Array[Int] = { val x2 = new Array[Int](5)
    val x6 = px6 // static data: Array(1,1,1,1,1)
    var x4 : Int = 0
    val x13 = while (x4 < 5) {
      val x5 = x2(0); val x7 = x6(x4); val x8 = x0(x4)
      val x9 = x7 * x8; val x10 = x5 + x9;
      val x11 = x2(0) = x10
      x4 = x4 + 1 }
    val x14 = x2(1); val x17 = x2(1) = x14
    val x22 = x2(2); val x24 = x2(2) = x22
    val x19 = x0(2); val x25 = x22 + x19
    val x26 = x2(2) = x25; val x27 = x2(3); val x29 = x2(3) = x27
    val x30 = x2(4); val x32 = x2(4) = x30
    val x33 = x30 + x19; val x34 = x2(4) = x33
    val x21 = x0(4); val x35 = x33 + x21; val x36 = x2(4) = x35
    x2 }}
```

Turning Interpreters into Compilers

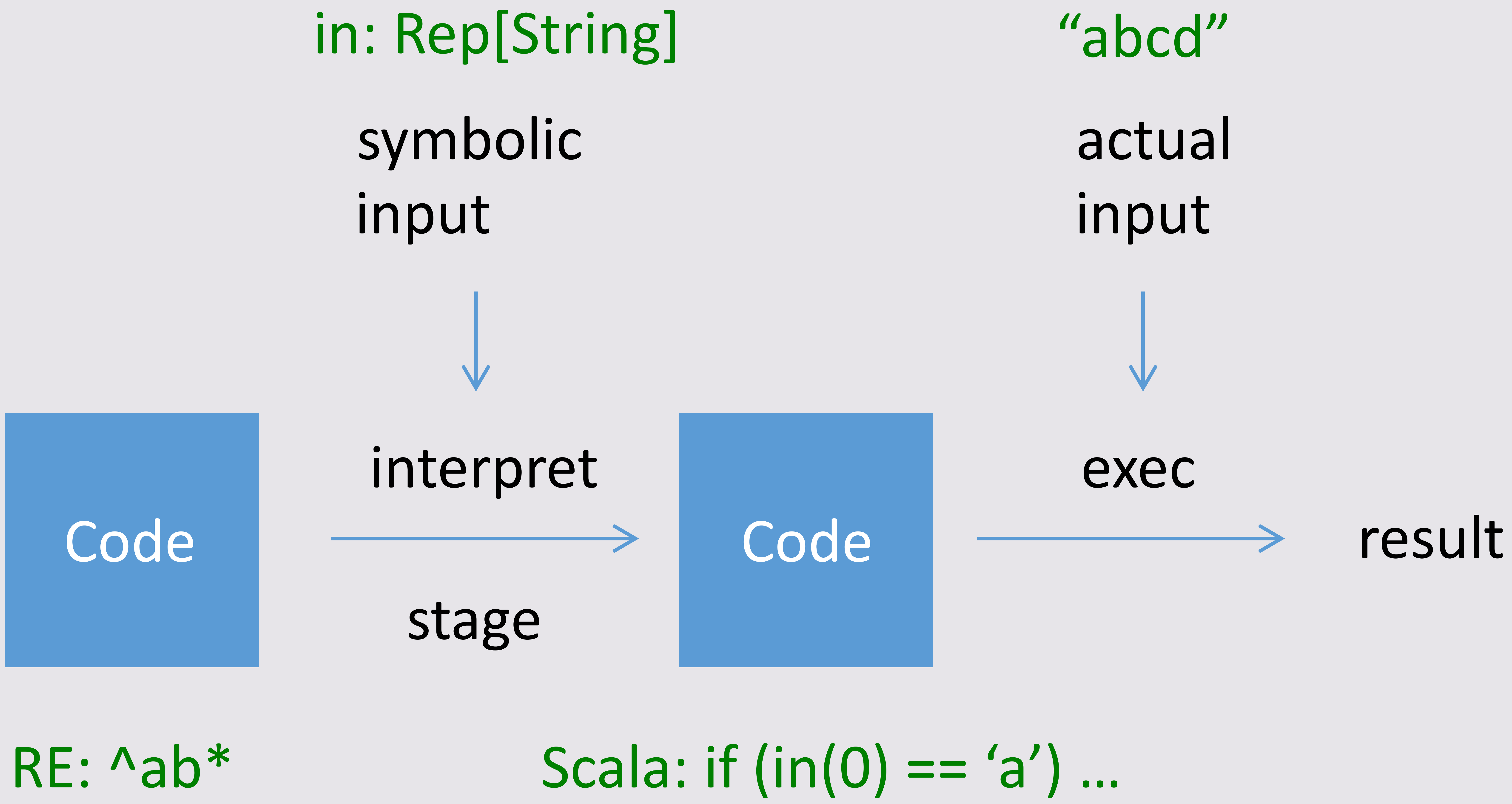
Turning Interpreters into Compilers




input
interpret
Code
result
stage
Code


input
interpret
Code
result
symbolic input
actual input
interpret
Code
stage
Code
exec
result

Turning interpreters into compilers



Usability Issues

- cognitive overhead of multi-level language
- notational overhead?
- multi-stage errors

puzzler 4

synthesis

Programming by Example

- f(1)=2, f(2)=3, …
- g(1)=2, g(2)=4, …
- h(1)=3, h(2)=5, …

SMT solver underspecified

- `(assert (and (= (f 1) 2) (= (f 2) 3)))`
- Model:
  `f(x) = if x=2 then 3 else if x=2 then 3 else 2`
- Try it: https://rise4fun.com/Z3/bpMYx

SMT solver overspecified

- ```
  (assert (forall ((x Int) (y Int))
    (=> (or (and (= x 1) (= y 2))
            (and (= x 2) (= y 3)))
        (= y (+ (* a x) b)))))
  ```

- Solution: a=1, b=1, so f(x)=x+1.

- Try it: https://rise4fun.com/Z3/HcJY
  ```

SMT solver full program

```
(declare-const a Int)
(declare-const b Int)
(define-fun f ((x Int)) Int (+ (* a x) b))
(assert (and (= (f 1) 2) (= (f 2) 3)))
(check-sat)
(get-model)
```

- Try it: https://rise4fun.com/Z3/jhr8

Usability Issues

- Trade–offs, e.g. between expressivity and decidability.
- Need to be precise induces cognitive overhead.
- Precision is brittle.
- Many ways to encode.

Why evaluation is hard

- Many conflicting dimensions: faster, safer, *easier*
- Does a new toolkit enable new ways
  - of thinking?
  - of programming?
  - of creating?

Discussion

What is particularly hard about evaluating methods for communicating with computers?

Group Projects

- Systems HCI requiring heavy-duty PL
  - Humans modifying DSLs for PBD (programming by demonstration)
  - Examplore with interactively defined templates
- Generic human-centered PL
  - Pick language feature, design it in a human-friendly way
  - Pick a language, describe how—and to what extent—its features are being used in the wild

- Usable + X (PL technique)
  - Usable Generative Programming
  - Usable Probabilistic Programming
  - Usable Type System / Verification
  - Usable Synthesis
    - inductive bias alignment between human and machine
    - ranking function improvements
    - DSL improvements
    - expressing constraints on intermediate states, i.e., equivalence values or types

Thank you!