Principled Programming

Introduction to Coding in Any Imperative Language

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Introduction

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It’s a subset of Java, Python, C/C++, JavaScript, …, (any imperative language).

Motivation

Can programming be mechanized?

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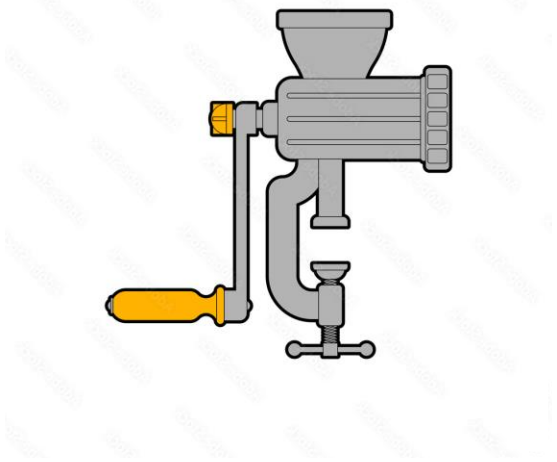
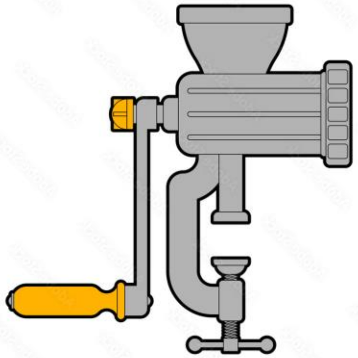
Requirements



Can programming be mechanized?



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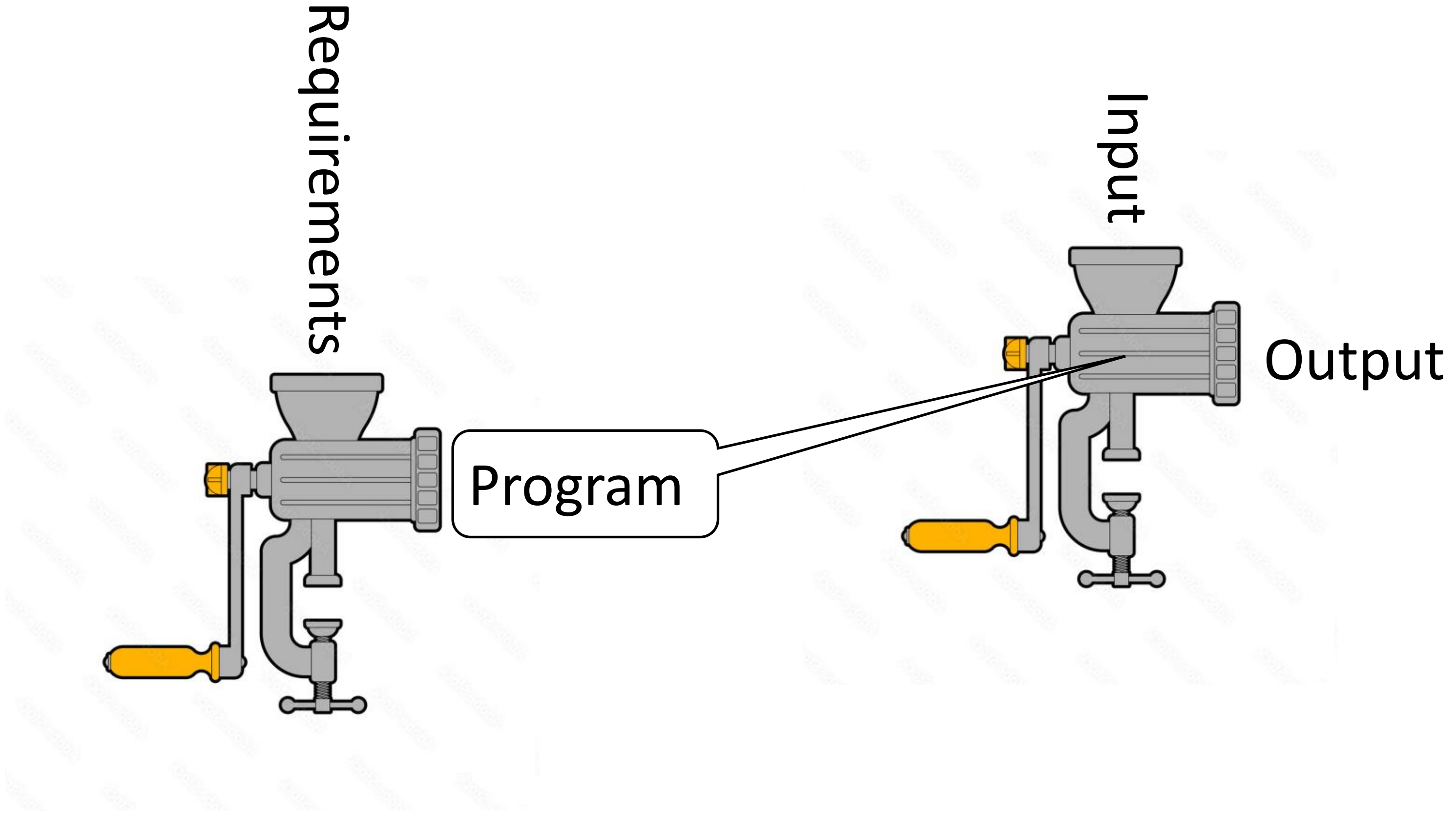

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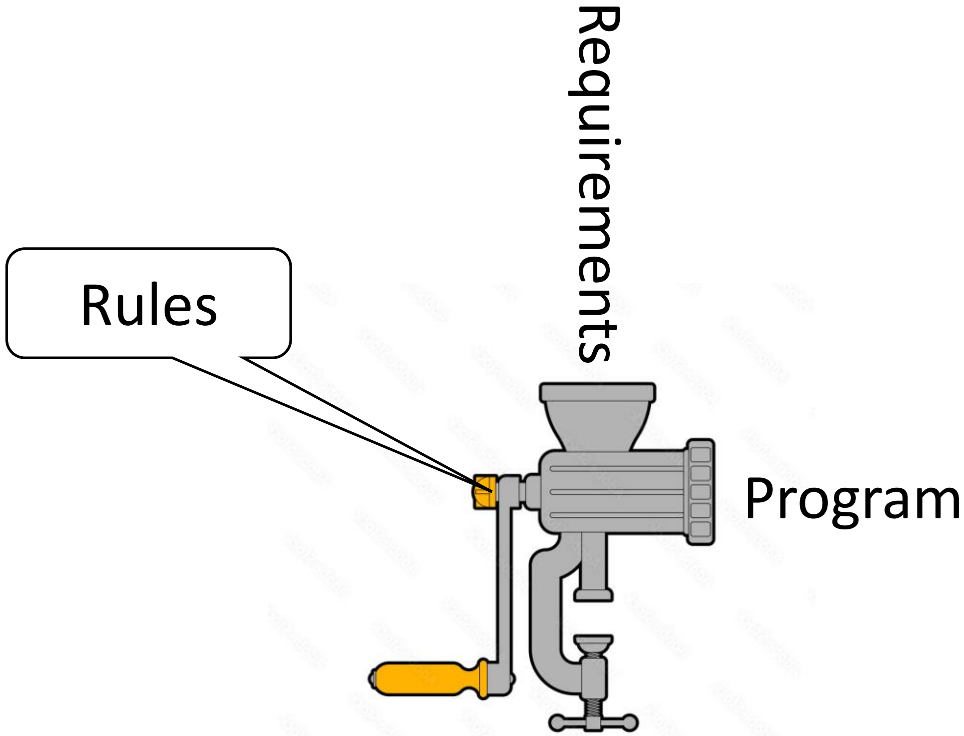
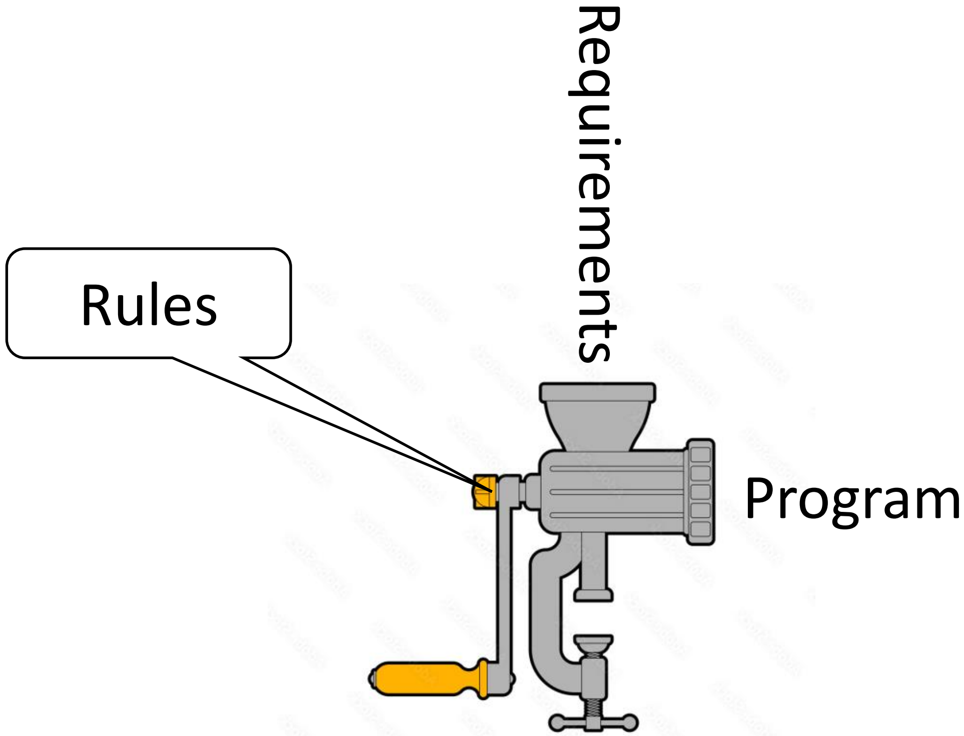


Fully-automatic programming would need rules that are:

- Effective
- Produce good code
- Efficient
- Complete

Motivation

Can programming be mechanized?



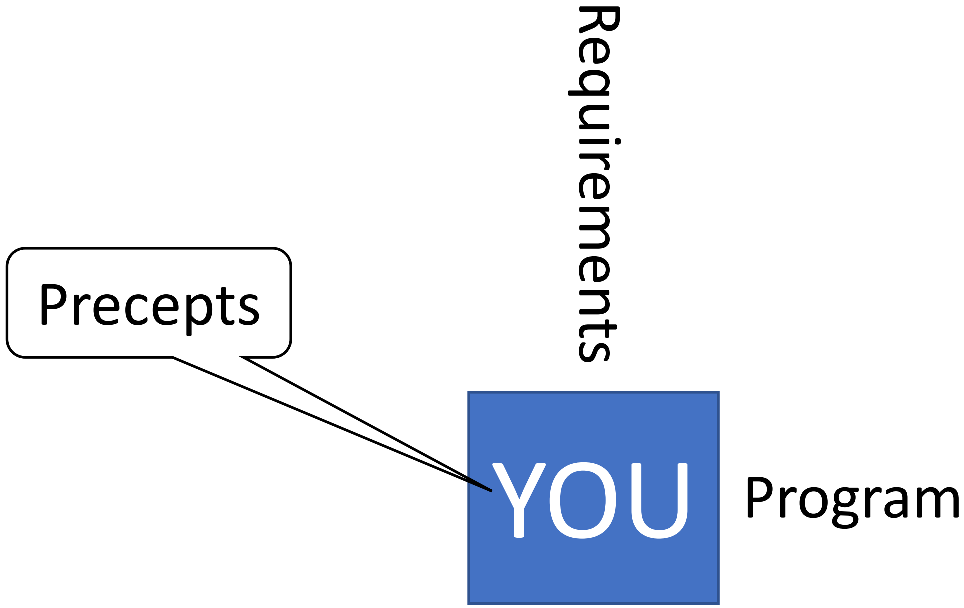
Fall back

- Rules for people
- Make programming
  - Easy
  - Accurate

Precepts

pre·cept

A command or principle intended especially as a general rule of action



Fall back

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A command or principle intended especially as a general rule of action

First Precept

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A command or principle intended especially as a general rule of action

First Precept

☞ **Follow programming precepts.**

pre·cept

A command or principle intended especially as a general rule of action

Second Precept

pre·cept

A command or principle intended especially as a general rule of action

Second Precept

☞ **Ignore precepts, when appropriate.**

pre·cept

A command or principle intended especially as a general rule of action

INCONSISTENCIES

☞ **Code with deliberation. Be mindful.**

Sample precept

Sample precept

☞ **Aspire to making code self-documenting by choosing descriptive names.**

Sample precept, with an application:

```
amount = price * quantity;
```

☞ **Aspire to making code self-documenting by choosing descriptive names.**

Same precept, with a different application:

```
piece = board[row+deltaRow[direction]][column+deltaColumn[direction]];
```

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Same precept, with a different application:

```
piece = board[row+deltaRow[direction]][column+deltaColumn[direction]];
```

```
piece = B[r+deltaR[d]][c+deltaC[d]];
```

☞ **Aspire to making code self-documenting by choosing descriptive names.**

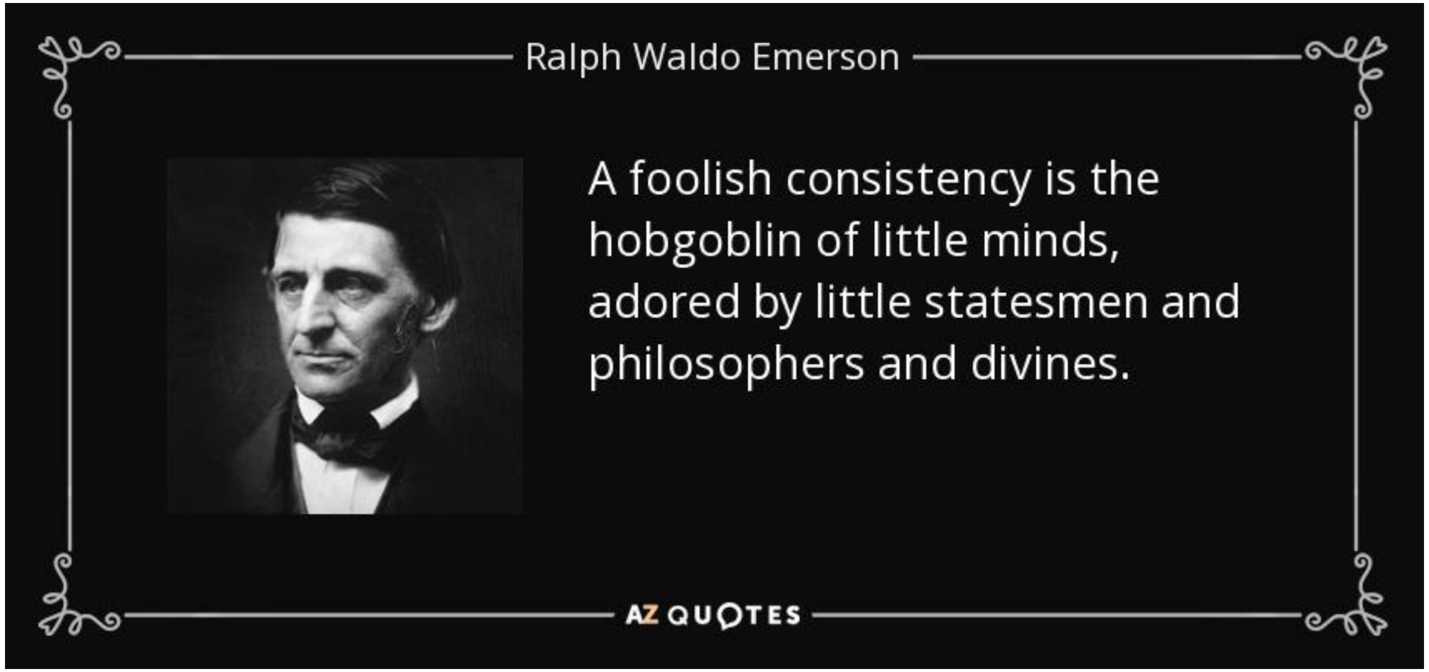
Alternative precept

```
piece = board[row+deltaRow[direction]][column+deltaColumn[direction]];

piece = B[r+deltaR[d]][c+deltaC[d]];
```

☞ **Use single-letter variable names when it makes code more understandable.**

Precepts



☞ **Resolve contradictory precepts with care.**

Exercise judgement

Make tradeoffs

Don’t make decisions casually

Indulge in personal preference

☞ **Resolve contradictory precepts with care.**

☞ **Be humble. Programming is hard and error prone. Respect it.**

Despite your humility, aim for perfection

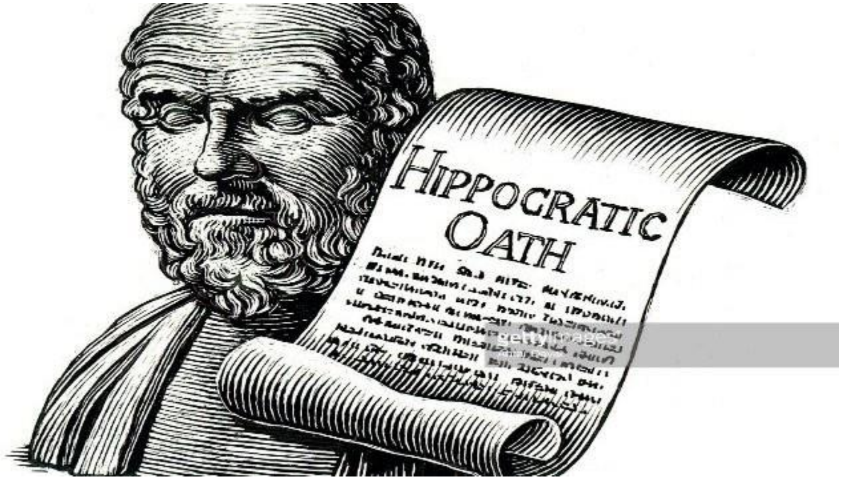
- The quality of the code you write
- The quality of the process you use to write it

☞ **Be humble. Programming is hard and error prone. Respect it.**

Process quality

☞ **Aspire to code it right the first time.**

Process quality: Hippocratic Coding



☞ **Aspire to code it right the first time. Do no harm. Avoid writing code that must be redone.**

An approach to Hippocratic Coding: Patterns

☞ **Master stylized code patterns, and use them.**

Sample programming problem

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Pattern: compute-use

```
/* Compute. */
/* Use. */
```

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Application of compute-use

```
/* Compute k. */
/* Use k. */
```

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Application of compute-use

```
/* Compute k. */
   k = thus-and-such;
/* Use k. */
   if ( /* k has some desired property */ ) /* Do this and that. */
```

☞ **Master stylized code patterns, and use them.**

Application of compute-use

```
/* Compute k. */
```

Smaller hairy mess

```
   k = thus-and-such;
/* Use k. */
   if ( /* k has some desired property */ ) /* Do this and that. */
```

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Another sample programming problem

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Another pattern: indeterminate iteration

```
/* Enumerate from start. */
   int k = start;
   while ( condition ) k++;
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Another pattern: indeterminate iteration

```
/* Enumerate from start. */
   int k = start;
   while ( condition ) k++;
```

Effect

Initialize k to *start*

Repeatedly add 1 to k

provided *condition* is **true**

☞ **Master stylized code patterns, and use them.**

Yet another pattern: general iterative computation

```
/* Initialize. */
while ( /* not finished */ ) {
   /* Compute. */
   /* Go on to next. */
   }
```

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Indeterminate iteration is an instance of the general interative-computation pattern.

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Shorthand: general iterative computation

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for (initialize; condition; go-on-to-next) compute
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Convention: We could use a **for**-statement to express indeterminate iteration

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for (initialize; condition; go-on-to-next) compute
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int k = start;
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Convention: We could use a **for**-statement to express indeterminate iteration

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for (int k=start; condition; go-on-to-next) compute
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Convention: We could use a **for**-statement to express indeterminate iteration

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for (int k=start; condition; k++) compute
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Convention: We could use a **for**-statement to express indeterminate iteration

```
for (int k=start; condition; k++);
```

```
int k = start;
while ( condition ) k++;
```

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But, by convention: Never use a **for**-statements for indeterminate iteration

```
for (int k=start; condition; k++);
```

```
int k = start;
while ( condition ) k++;
```

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Convention: Reserve **for**-statements for determinate iteration

```
for (int k=start; k<limit; k++) compute
for (int k=start; k<=limit; k++) compute
```

k goes up

```
for (int k=start; k>limit; k--) compute
for (int k=start; k>=limit; k--) compute
```

k goes down

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Another approach to Hippocratic Coding: Analysis

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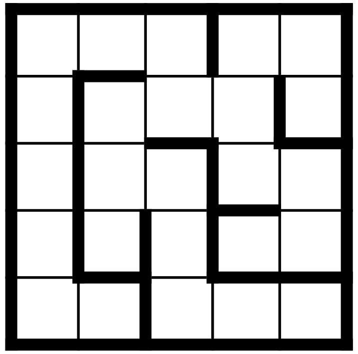
Another approach to Hippocratic Coding: Analysis

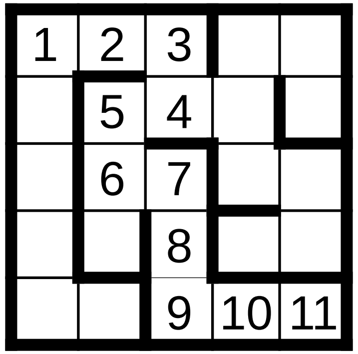
☞ **Analyze first.**

Example: Running a Maze

Background. Define a maze to be a square two-dimensional grid of cells separated (or not) from adjacent cells by walls. One can move between adjacent cells if and only if no wall divides them. A solid wall surrounds the entire grid of cells, so there is no escape from the maze.

Problem Statement. Write a program that inputs a maze, and outputs a direct path from the upper-left cell to the lower-right cell if such a path exists, or outputs "Unreachable" otherwise. A path is direct if it never visits any cell more than once.





Analysis

- Problem
- Architecture
- Data
- Components

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Analysis

Problem

☞ **Make sure you understand the problem.**

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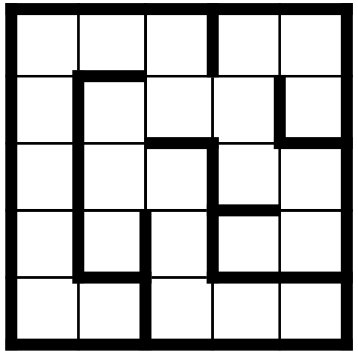
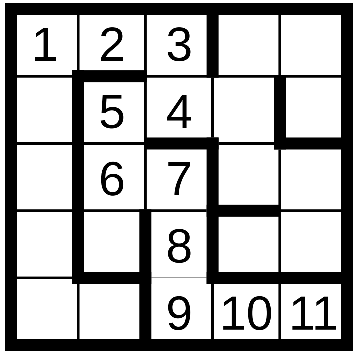
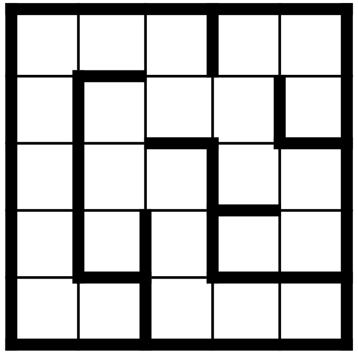


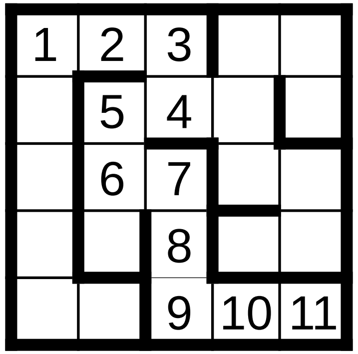


☞ **Make sure you understand the problem.**

Example: Running a Maze

- Do I understand each noun: *maze*, *grid*, *cell*, *wall*, *path*, and *direct path*?
- Do I understand the verbs: Specifically, how does one *move* between cells?
- How is a maze represented in the input?
- Is there any upper limit on the size of a maze? Is there a lower limit?
- What is the expected program behavior if the input is not well-formed?
- Is a direct path the same as a shortest path?
- What if there is more than one direct path?
- How is a path to be displayed in the output?





☞ **Make sure you understand the problem.**

Architecture: What sort of computation will it be?

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- **Online**. Read a sequence of inputs, and process them on the fly.
- **Offline**. Read all inputs, perform a computation, output result.
- **Other**.

Architecture: Offline computation pattern

```
/* Input. */
/* Compute. */
/* Output. */
```

Architecture: Restate the problem on the architecture

```
/* Input a maze of arbitrary size, or output “malformed input” and stop if the
   input is improper. Input format: TBD. */
/* Compute a direct path through the maze, if one exists. */
/* Output the direct path found, or “unreachable” if there is none. Output
   format: TBD. */
```

Programs: Instructions for manipulating values

Instructions: code

Values: data

Patterns and Architecture: Code-centered perspective

☞ **Dovetail thinking about code and data.**

Code

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Data

maze

```
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```

path

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External Data

external data (maze)

```
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```

internal data (path)

☞ **Dovetail thinking about code and data.**

Variables

```
/* Input a maze of arbitrary size, or output “malformed input” and stop if the
   input is improper. Input format: TBD. */
```

maze

```
/* Compute a direct path through the maze, if one exists. */
```

path

```
/* Output the direct path found, or “unreachable” if there is none. Output
   format: TBD. */
```

☞ **Specify how individual program steps will cooperate with one another.**

Internal Data

```
/* Input a maze of arbitrary size, or output “malformed input” and stop if the
   input is improper. Input format: TBD. */
```

internal data (maze)

```
/* Compute a direct path through the maze, if one exists. */
```

internal data (path)

```
/* Output the direct path found, or “unreachable” if there is none. Output
   format: TBD. */
```

☞ **A program’s internal data representation is central to the code; consider it early.**

External Data

external data (maze)

```
/* Input a maze of arbitrary size, or output “malformed input” and stop if the
   input is improper. Input format: TBD. */
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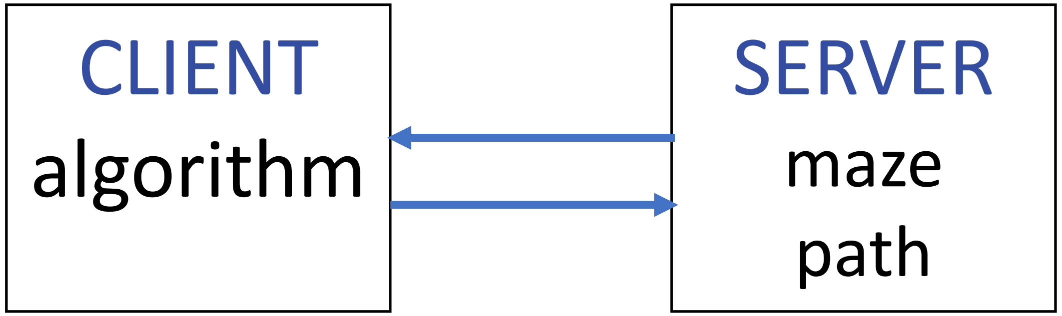
```

internal data (path)

☞ **Consider a program’s external data representation late.**

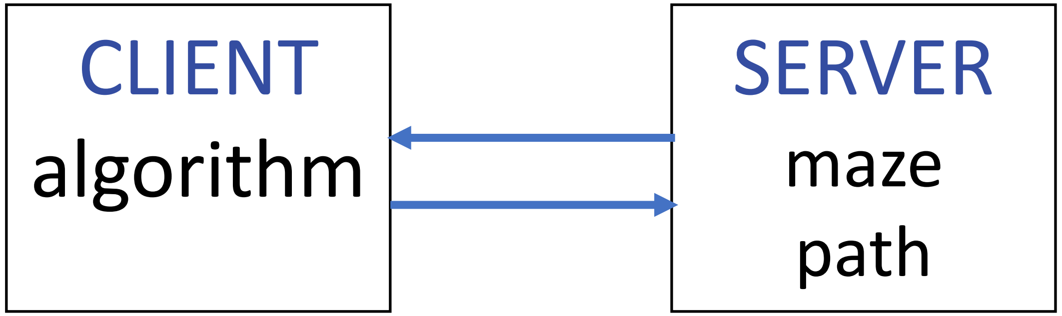
Components

- A program can be organized into components.
- Distinguish between the maze-running algorithm (a client of data) and the data itself (housed in a server).
- What operations are needed by the client?
- What operations can be provided by the server?
- Resolve differences by negotiation.



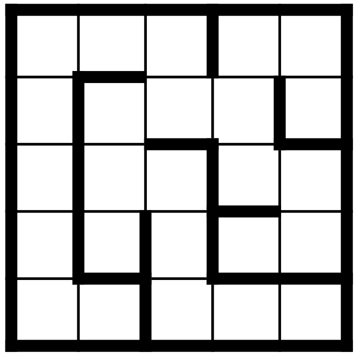
Components

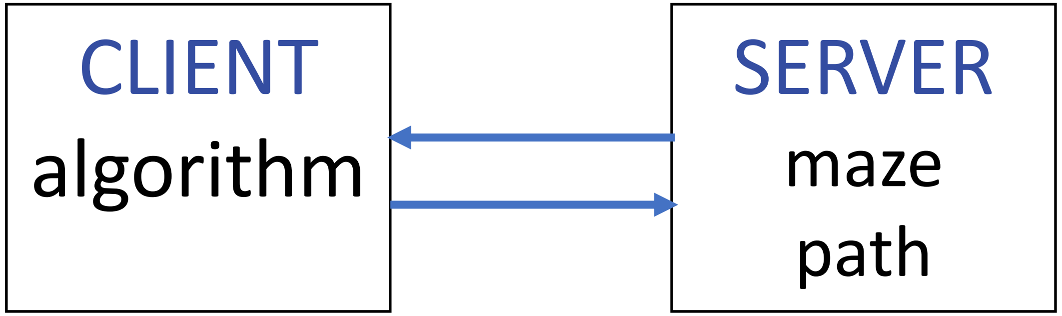
- Some aspects of data are static, i.e., don't change (maze)
- The client learns of static data by queries.
- Other aspects of data are dynamic, i.e., change (path)
- The client is an actor that effects changes by actions:
  - extend path (if possible); retract path (if necessary)
  - The cumulative effect of actions is recorded in state.



Components

- A client may have/want global perspective
  - algorithm is aware of the full maze





Components

- A client may have/want global perspective
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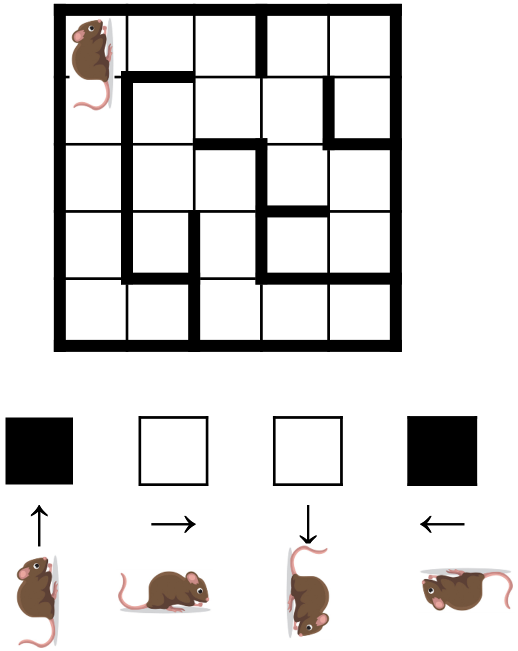
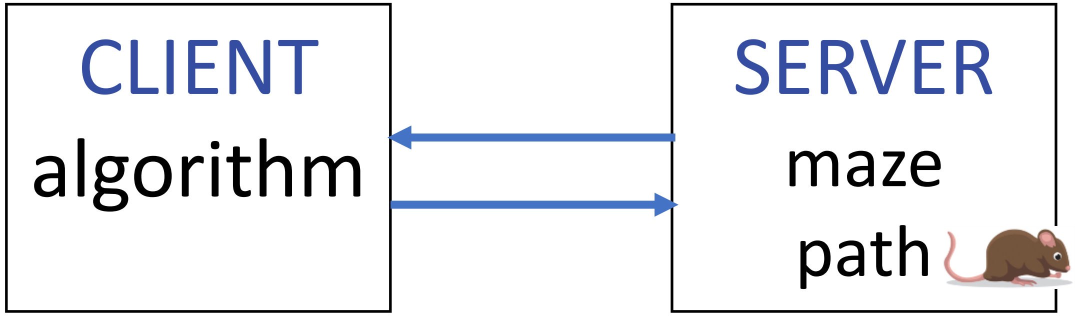
- Other clients have/want only local perspective
  - rat is unaware of full maze





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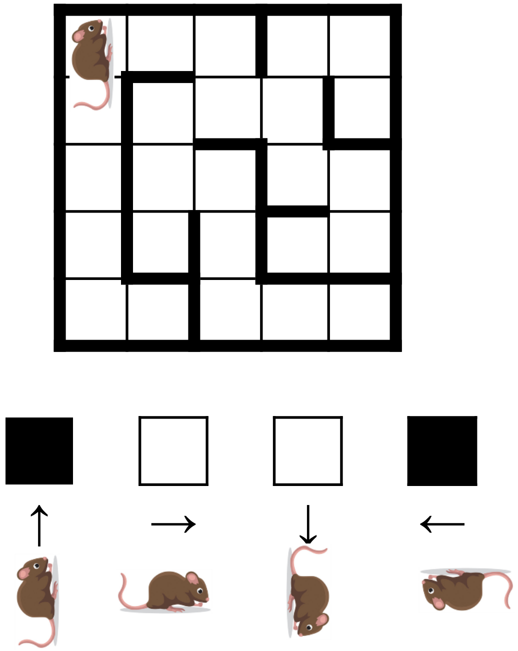
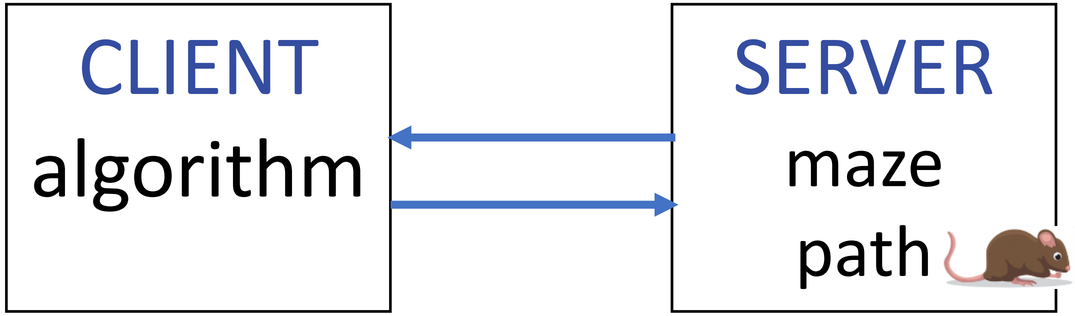




Analysis

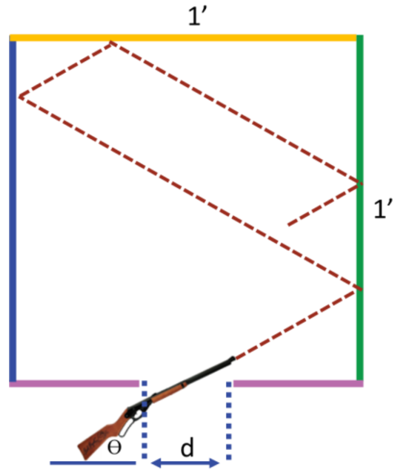
Another programming problem

☞ **Analyze first.**

Example: Ricocheting Bee-Bee

Background. A square tin box measuring one foot on each side has a slit of size d centered on one side. Insert a bee-bee gun at the center of the slit at angle Θ, and shoot. The bee-bee ricochets off sides, one after another. On each ricochet, the angle of reflection is equal to the angle of incidence.

Problem Statement. Write a program that inputs d and Θ, and outputs the total distance the bee-bee travels before it exits.



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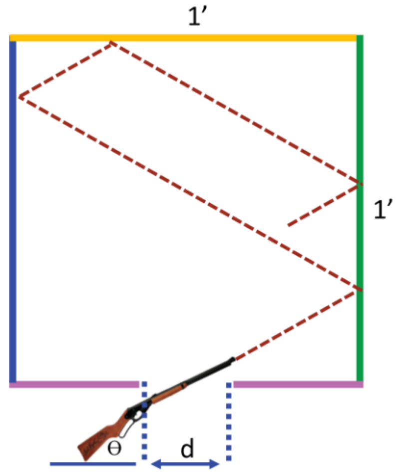

☞ **Analyze first.**

Example: Output the sum of the integers between 1 and n

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```
/* Output the sum of 1 through n. */
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```
/* Output the sum of 1 through n. */
   int sum = 0;
   for (int k=1; k<=n; k++) sum = sum + k;
   System.out.println( sum );
```

knee-jerk, brute force

Example: Output the sum of the integers between 1 and n

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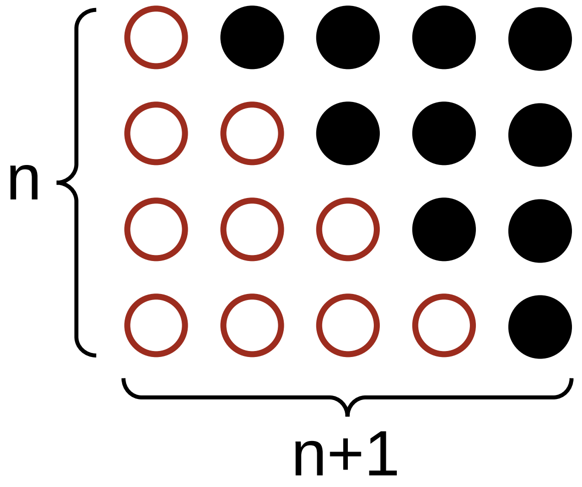
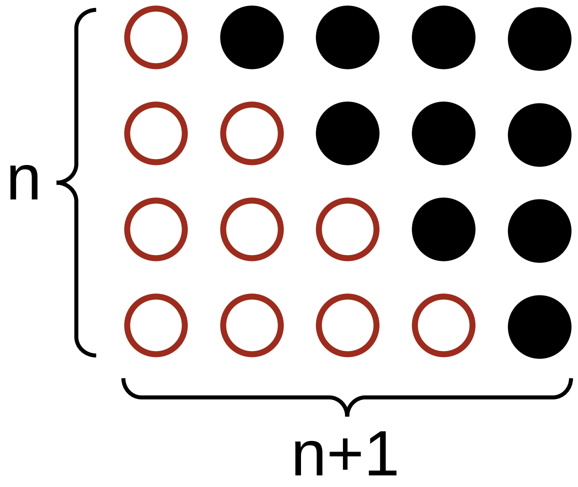
   System.out.println( sum );
```



☞ **Analyze first.**

Example: Output the sum of the integers between 1 and n

```
/* Output the sum of 1 through n. */
   System.out.println( n*(n+1)/2 );
```



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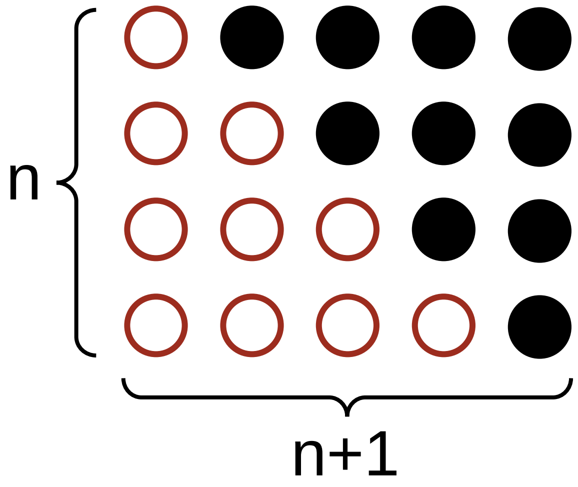
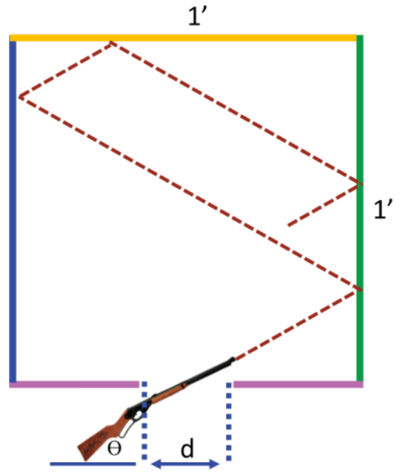


☞ **Sometimes iteration is unnecessary because a closed-form solution is available.**

Example: Ricocheting Bee-Bee

Background. A square tin box measuring one foot on each side has a slit of size d centered on one side. Insert a bee-bee gun at the center of the slit at angle Θ, and shoot. The bee-bee ricochets off sides, one after another. On each ricochet, the angle of reflection is equal to the angle of incidence.

Problem Statement. Write a program that inputs d and Θ, and outputs the total distance the bee-bee travels before it exits.



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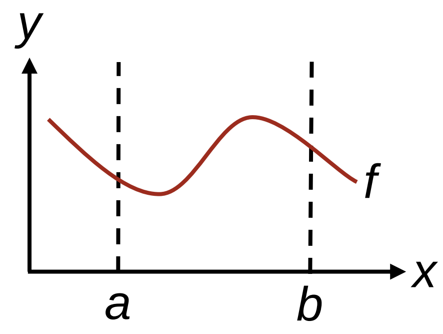
Analogy: A possible source of inspiration

Analogy: Computing arc length s of a curve y=*f(x),* between a and b.



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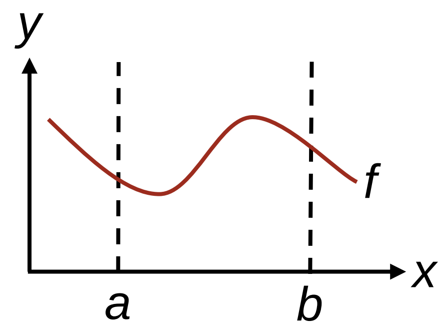

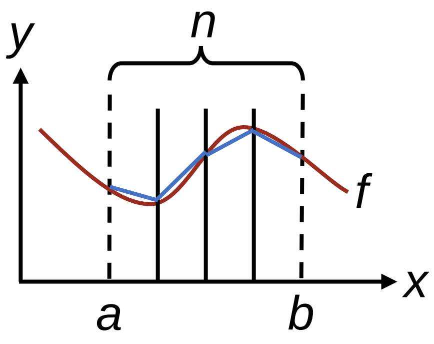

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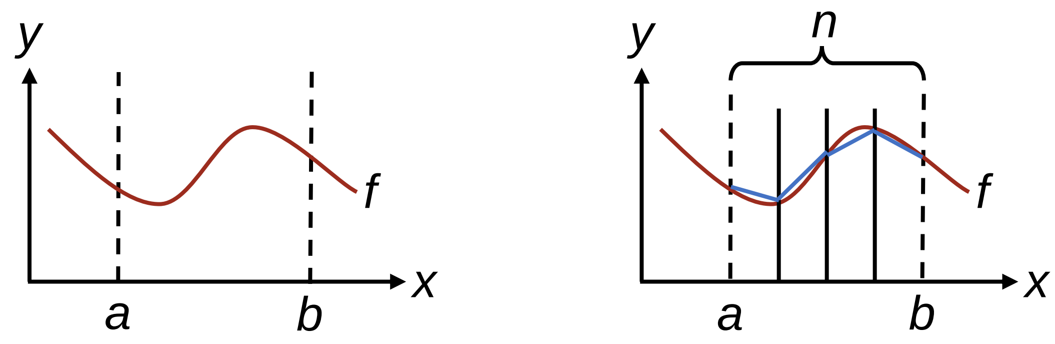
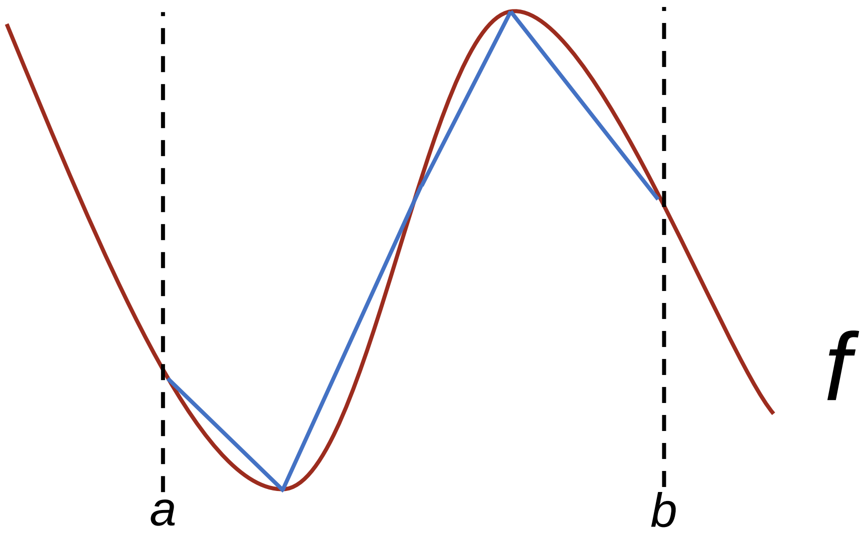
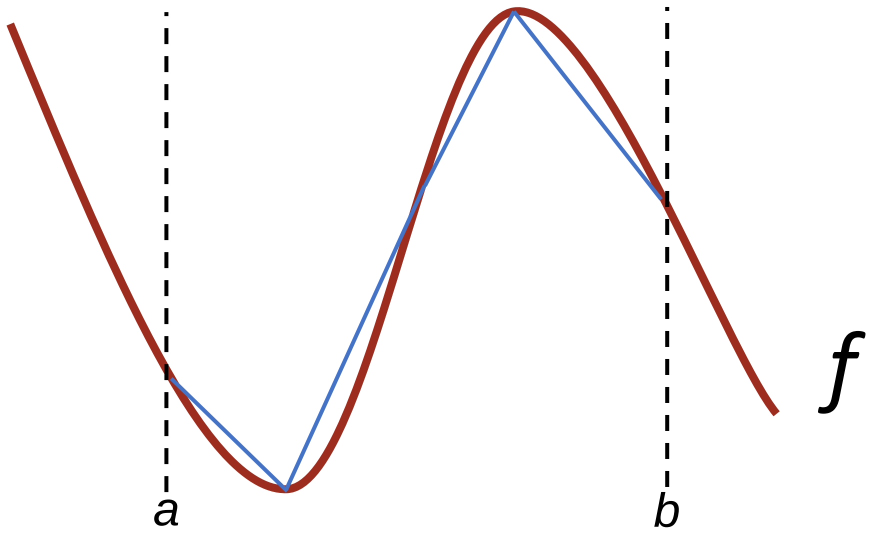


$$s = \int_a^b \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\; dx$$

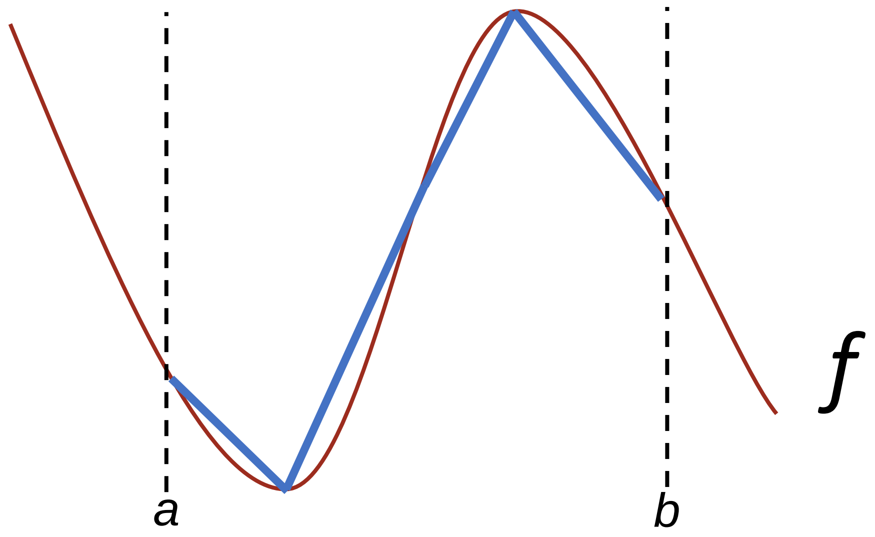
Analogy: Where does the analogy faulter?



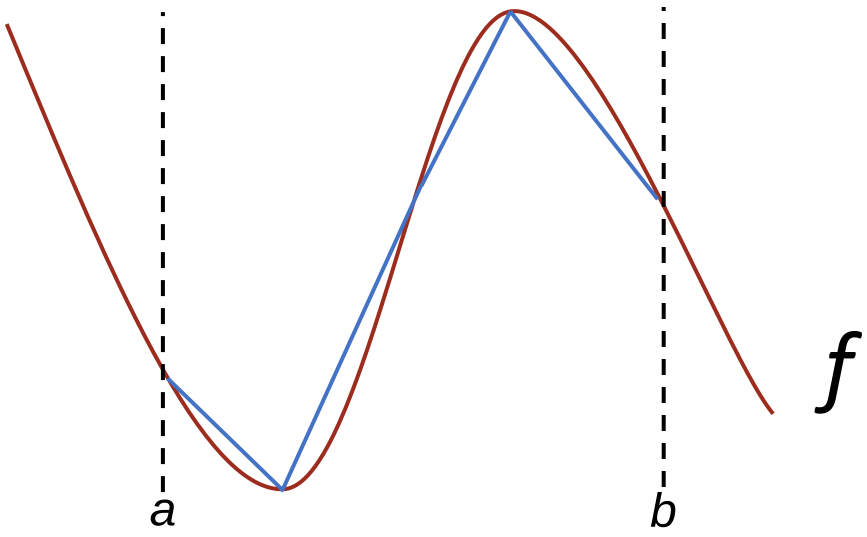
Analogy: In the calculus problem, we seek the length of f



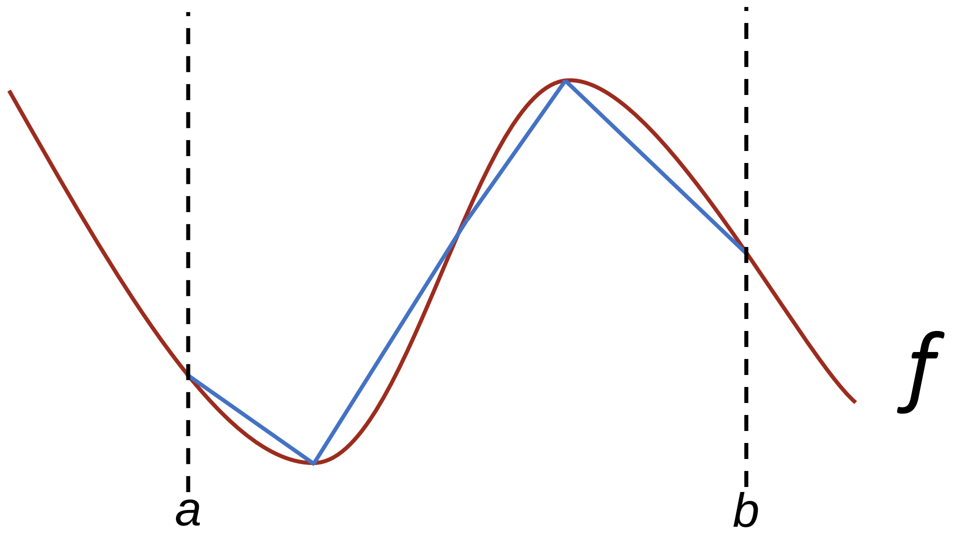
Analogy: In the bee-bee problem, we seek the total lengths of the pieces



Analogy: How can we unify the two points of view?



Analogy: By finding a related problem where they are the same.



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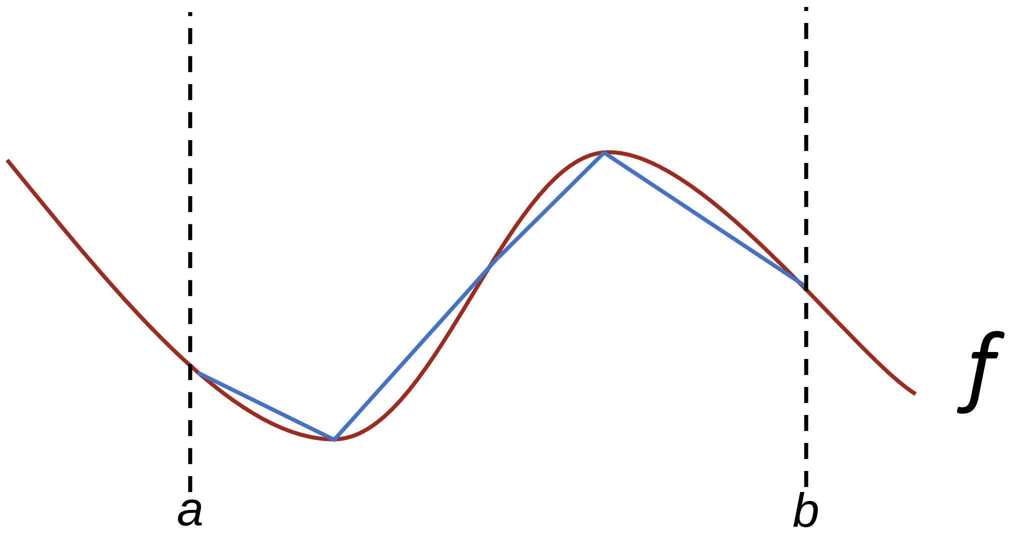

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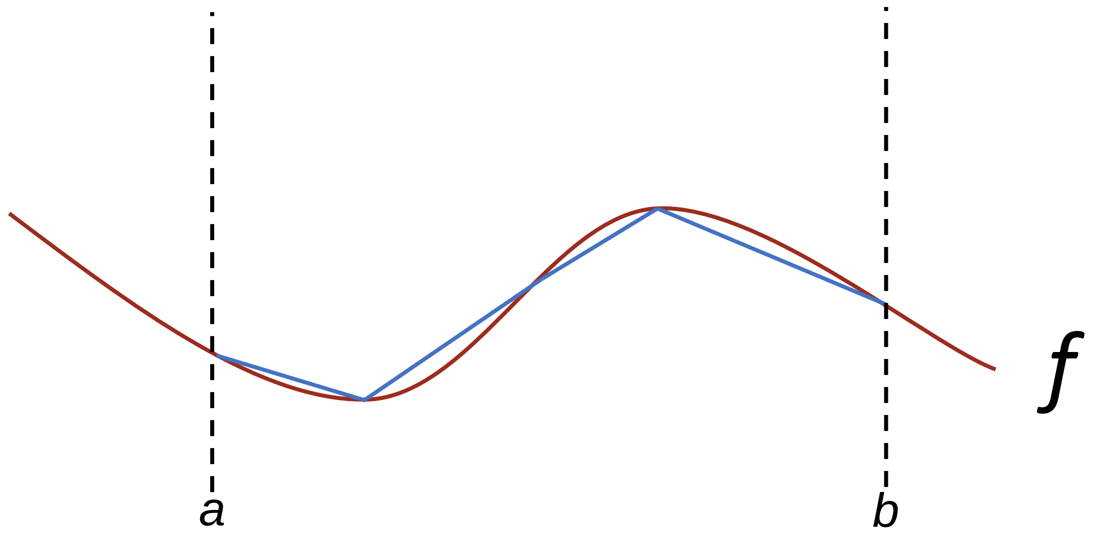

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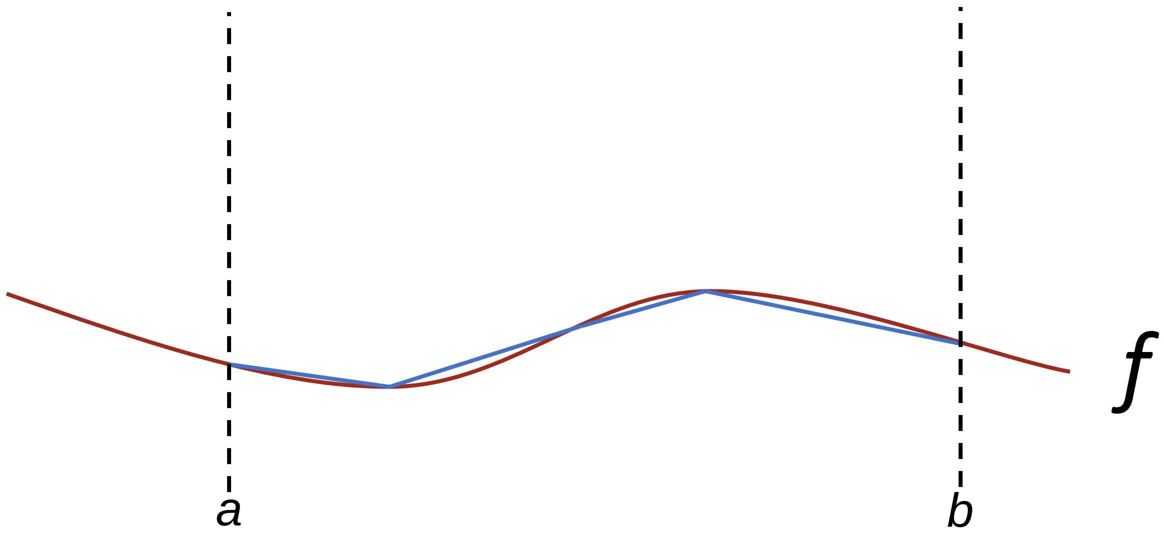

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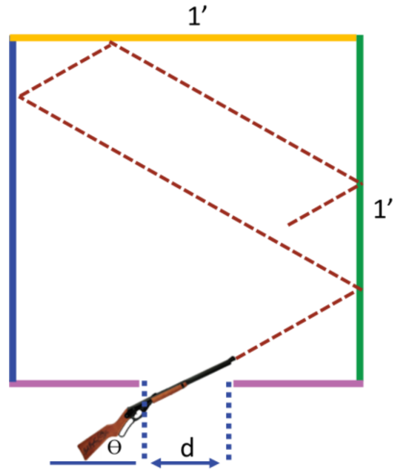

☞ **Solve a different problem, and use that solution to solve the original problem.**

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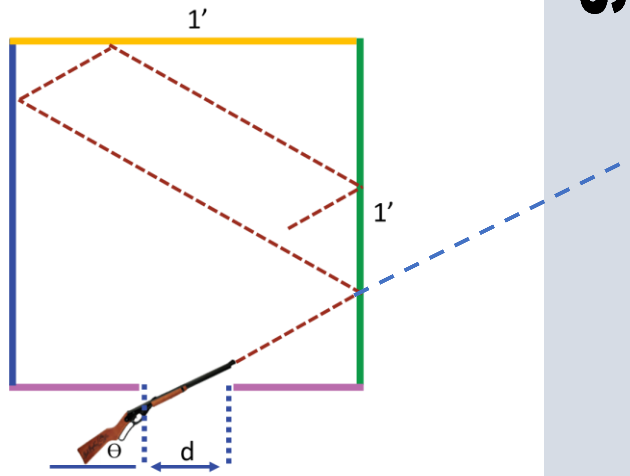

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Analysis

Example: Ricocheting Bee-Bee

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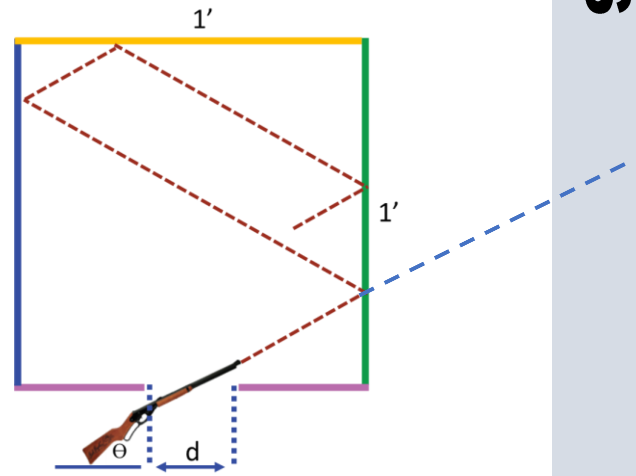

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Hippocratic Coding:-

- ☞ Aspire to code it right the first time.

Patterns:

- ☞ Master stylized code patterns, and use them.

Analysis:

- ☞ Analyze first.

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Analysis:

☞ **Analyze first.**

Process:

☞ **Mitigate errors.**

Process: Don’t make mistakes

- Hope for the best, but
- Plan for the worst.

☞ **Avoid debugging like the plague.**

Process: Find mistakes as soon as possible

☞ **Test programs incrementally.**

Process: Stay in control

- Define relevant subproblems that can be tested.
- Preserve end-to-end correctness

☞ **Never be (very) lost. Don’t stray far from a correct (albeit, partial) program.**

Process: Subproblem end-to-end correctness

```
/* Input a maze of arbitrary size, or output “malformed input” and stop if the
   input is improper. Input format: TBD. */
/* Compute a direct path through the maze, if one exists. */
/* Output the direct path found, or “unreachable” if there is none. Output
   format: TBD. */
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Process: Undo if necessary

☞ **Don’t be wedded to code. Revise and rewrite when you discover a better way.**

Process: Stepwise refinement

☞ **Program top-down, outside-in.**

Example: Print the integer part of the square root of an integer `n≥0`.

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/* Given n≥0, output the Integer Square Root of n. */
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Example: Print the integer part of the square root of an integer `n≥0`.

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Example

```
/* Given n≥0, output the Integer Square Root of n. */
```

Example

```
/* Given n≥0, output the Integer Square Root of n. */          1
```

☞ **Make sure you understand the problem.**

```
/* Given n≥0, output the Integer Square Root of n. */
```
1

Where did n come from?

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/* Given n≥0, output the Integer Square Root of n. */    1
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- It is a program variable

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/* Given n≥0, output the Integer Square Root of n. */     1
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Where did n come from?

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- It is assumed to already contain a value ≥0

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```
/* Given n≥0, output the Integer Square Root of n. */    1
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Where did n come from?

- It is a program variable
- It is assumed to already contain a value ≥0
- We are asked to write a program segment

☞ **Make sure you understand the problem.**

Example

```
/* Given n≥0, output the Integer Square Root of n. */    1
```

☞ **Make sure you understand the problem.**

```
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```
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Can’t we just do this using a few library routines?

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```
/* Given n≥0, output the Integer Square Root of n. */
   System.out.println( Math.floor( Math.sqrt(n) ) );
```

2

Can't we just do this using a few library routines?

- Yes.

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/* Given n≥0, output the Integer Square Root of n. */
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Can't we just do this using a few library routines?

- Yes.
- But that would deprive us of a good example.
- So, we amend our problem statement.

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Example: Print the integer part of the square root of an integer n≥0 without using built-in functions.

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```

Example: Print the integer part of the square root of an integer $n \geq 0$ without using built-in functions.

Example

```
/* Given n≥0, output the Integer Square Root of n. */
```

☞ **Master stylized code patterns, and use them.**

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/* Given n≥0, output the Integer Square Root of n. */
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Example

```
/* Given n≥0, output the Integer Square Root of n. */
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```
/* Compute. */
/* Use. */
```

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/* Given n≥0, output the Integer Square Root of n. */
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1

```
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/* Use r. */
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☞ **Specify how individual program steps will cooperate with one another.**

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/* Given n≥0, output the Integer Square Root of n. */
   /* Let r be the integer part of the square root of n≥0. */
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☞ **If you "smell a loop", write it down.**

Example

Example

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   /* Let r be the integer part of the square root of n≥0. */
   System.out.println( r );
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☞ **Decide first whether an iteration is indeterminate (use while) or determinate (use for).**

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/* Indeterminate iteration */
   int k = start;
   while ( condition ) k++;
```

Which?

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3

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☞ **There is no shame in reasoning with concrete examples.**

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☞ **Elaborate the expected input/output mapping explicitly.**

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r	r*r	n
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2	4	4, 5, 6, 7, 8
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But what is special about 3?
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☞ **Alternate between concrete reasoning and abstract reasoning.**

Example

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/* Given n≥0, output the Integer Square Root of n. */                    4
   /* Let r be the integer part of the square root of n≥0. */
      int r = 0;
      while ( (r+1)*(r+1) ____ n ) r++;
   System.out.println( r );
```

r	r*r	n
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      while ( (r+1)*(r+1) ____ n ) r++;
   System.out.println( r );
```

4

☞ **Alternate between concrete reasoning and abstract reasoning.**

```
/* Given n≥0, output the Integer Square Root of n. */
   /* Let r be the integer part of the square root of n≥0. */
      int r = 0;
      while ( (r+1)*(r+1) ____ n ) r++;
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Elaborate and eliminate choices

☞ **Alternate between concrete reasoning and abstract reasoning.**

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Elaborate and eliminate choices for the relation

==, != No. Given r, must be true for many n, and false for many n.

☞ **Alternate between concrete reasoning and abstract reasoning.**

Example

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/* Given n≥0, output the Integer Square Root of n. */
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Elaborate and eliminate choices for the relation

==, != No. Given r, must be true for many n, and false for many n.

>, >= No. Must keep going for little r and big n.

☞ **Alternate between concrete reasoning and abstract reasoning.**

Example

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/* Given n≥0, output the Integer Square Root of n. */                    4
   /* Let r be the integer part of the square root of n≥0. */
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```

Elaborate and eliminate choices for the relation

==, !=	No. Given r, must be true for many n, and false for many n.
>, >=	No. Must keep going for little r and big n.
<	No. Must keep going for "equal n" case.

☞ **Alternate between concrete reasoning and abstract reasoning.**

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   /* Let r be the integer part of the square root of n≥0. */
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Elaborate and eliminate choices for the relation

==, !=	No. Given r, must be true for many n, and false for many n.
>, >=	No. Must keep going for little r and big n.
<	No. Must keep going for "equal n" case.
<=	Yes.

☞ **Alternate between concrete reasoning and abstract reasoning.**

Example

```
/* Given n≥0, output the Integer Square Root of n. */
   /* Let r be the integer part of the square root of n≥0. */
      int r = 0;
      while ( (r+1)*(r+1) <= n ) r++;
   System.out.println( r );
```

5

Elaborate and eliminate choices for the relation

==, !=	No. Given r, must be true for many n, and false for many n.
>, >=	No. Must keep going for little r and big n.
<	No. Must keep going for "equal n" case.
<=	Yes.

☞ **Alternate between concrete reasoning and abstract reasoning.**

Example

```
/* Given n≥0, output the Integer Square Root of n. */
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5

Pragmatics

- For a full program, we need
  - Get a value for n
  - A receptacle for our code (`boilerplate`)
  - A mechanism for input (`Scanner`)
  - A named operation to invoke (`main`)

```
/* Output the Integer Square Root of an integer input. */
   /* Obtain an integer n≥0 from the user. */
   /* Given n≥0, output the Integer Square Root of n. */
      /* Let r be the integer part of the square root of n≥0. */
         int r = 0;
         while ( (r+1)*(r+1) <= n ) r++;
      System.out.println( r );
```

6

Pragmatics

- For a full program, we need
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import java.util.Scanner;
class boilerplate {
   static Scanner in = new Scanner(System.in);
   static void main() {
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         /* Given n≥0, output the Integer Square Root of n. */
            /* Let r be the integer part of the square root of n≥0. */
               int r = 0;
               while ( (r+1)*(r+1) <= n ) r++;
            System.out.println( r );
      } /* main */
   } /* boilerplate */
```

Pragmatics

- For a full program, we need
  - Get a value for n
  - A receptacle for our code (boilerplate and main)
  - A mechanism for input (Scanner)
  - A named operation to invoke (main)

Pragmatics

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      } /* main */
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```

7

Pragmatics

- For a full program, we need
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  - A mechanism for input (Scanner)
  - A named operation to invoke (main)

```
import java.util.Scanner;
class boilerplate {
   static Scanner in = new Scanner(System.in);
   static void main() {
      /* Output the Integer Square Root of an integer input. */
         /* Obtain an integer n≥0 from the user. */
            int n = in.nextInt();
         /* Given n≥0, output the Integer Square Root of n. */
            /* Let r be the integer part of the square root of n≥0. */
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               while ( (r+1)*(r+1) <= n ) r++;
            System.out.println( r );
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               while ( (r+1)*(r+1) <= n ) r++;
            System.out.println( r );
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```
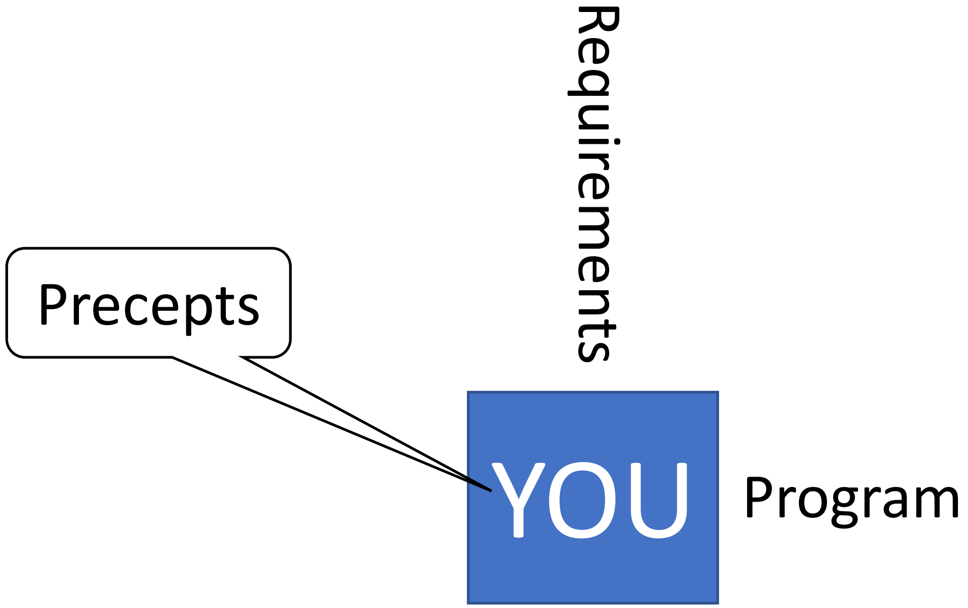
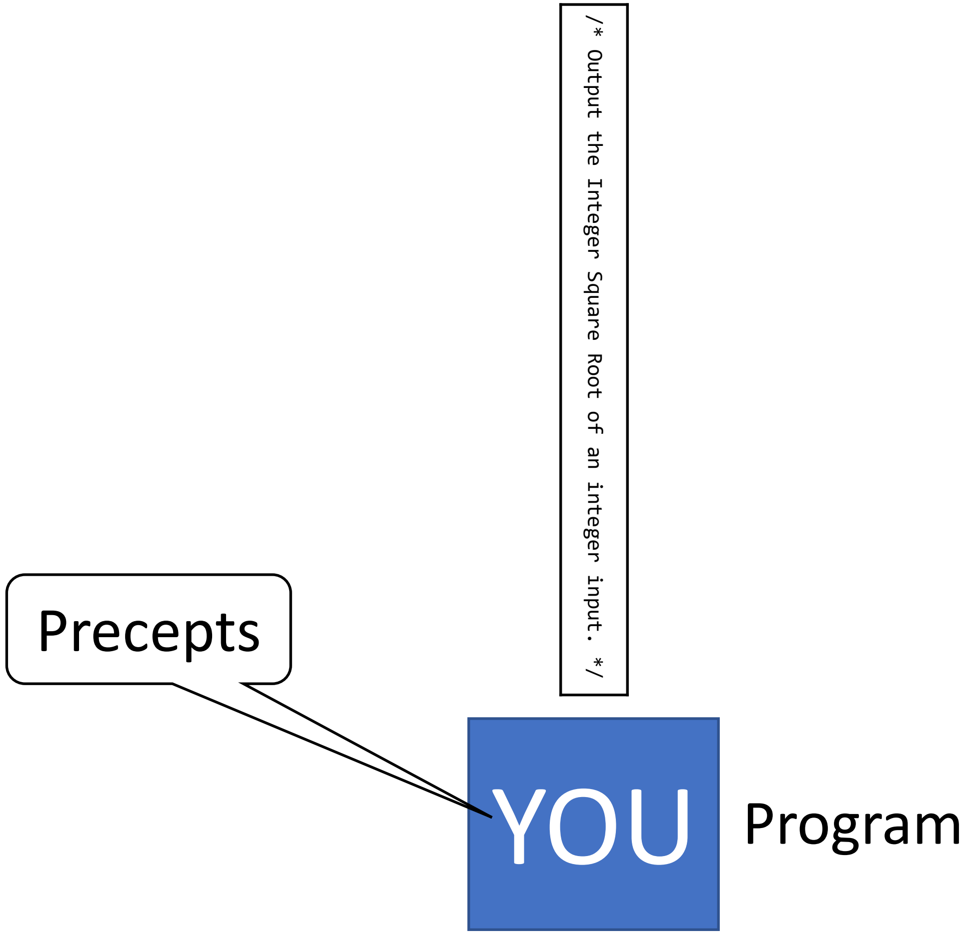

8

Pragmatics



Pragmatics


/* Output the Integer Square Root of an integer input. */
Precepts
YOU
Program

Pragmatics

/* Output the Integer Square Root of an integer input. */

Precepts

YOU

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import java.util.Scanner;
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Pragmatics

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Pragmatics

Precepts

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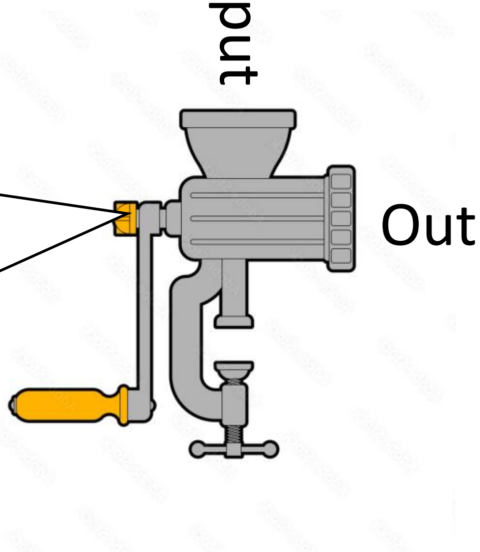

Pragmatics

Precepts

YOU

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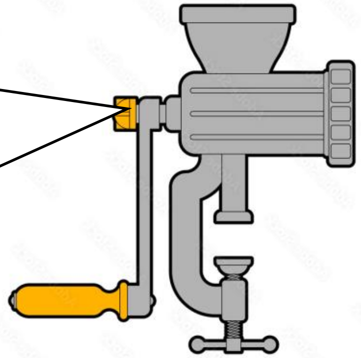

Output

Pragmatics

Precepts

YOU

/* Output the Integer Square Root of an integer input. */

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class boilerplate {
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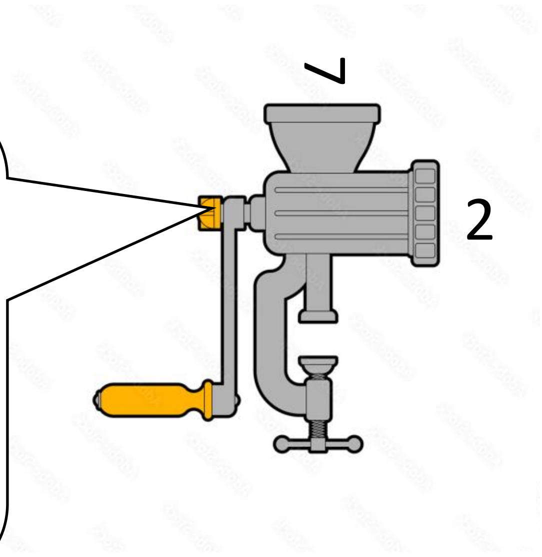

Summary

Goals

Elements of methodology

- Precepts, Patterns, Analysis, Process

Core programming-language constructs

- (almost all that we will need)

Illustrated the approach with a complete example