

```
x: Integer = 42  
y: Float = sin(x)  
z: String = "Value"
```

Type Checking

And use **Perspectives** (often combined)

```
assert(x >= 0)  
a <- angleCmp(x)  
  
verify(  
    0 <= a &&  
    a <= 40  
)
```

Verification

```
for (i in 1:n) {  
    sum <- sum + i  
}  
▼  
sum <- n*(n+1)/2
```

Optimization

```
x <- 42  
if (x < 0) {  
    print("Negative")  
} # Dead Code
```

Clustering

Linting

```
inp <- read.csv("data.csv")  
clean <- filter(inp, a>5)  
plot(inp$a, inp$a)
```

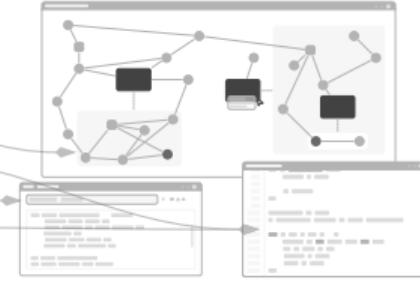
Some of those are the result of other analyses or dynamic analyses

Slicing

```
x <- u + 0  
print(x)  
▼  
y <- u + 0  
print(y)
```

Refactoring

And **Communicate** or **Use** results



A Primer on Static Code Analysis

Software Quality Assurance – Static Code Analysis, I | Florian Sihler | December 3, 2025



Software Engineering
Programming Languages

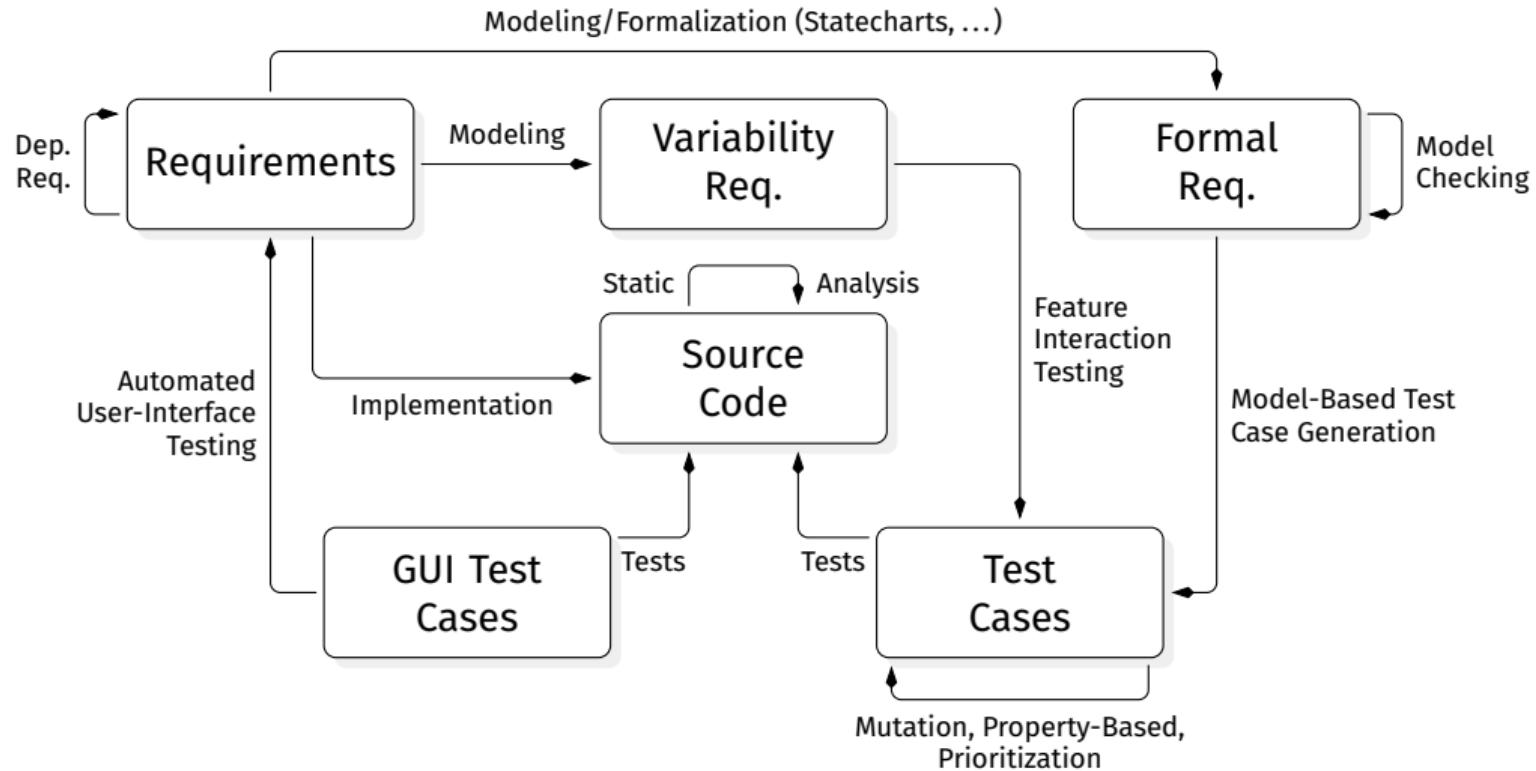


universität
uulm

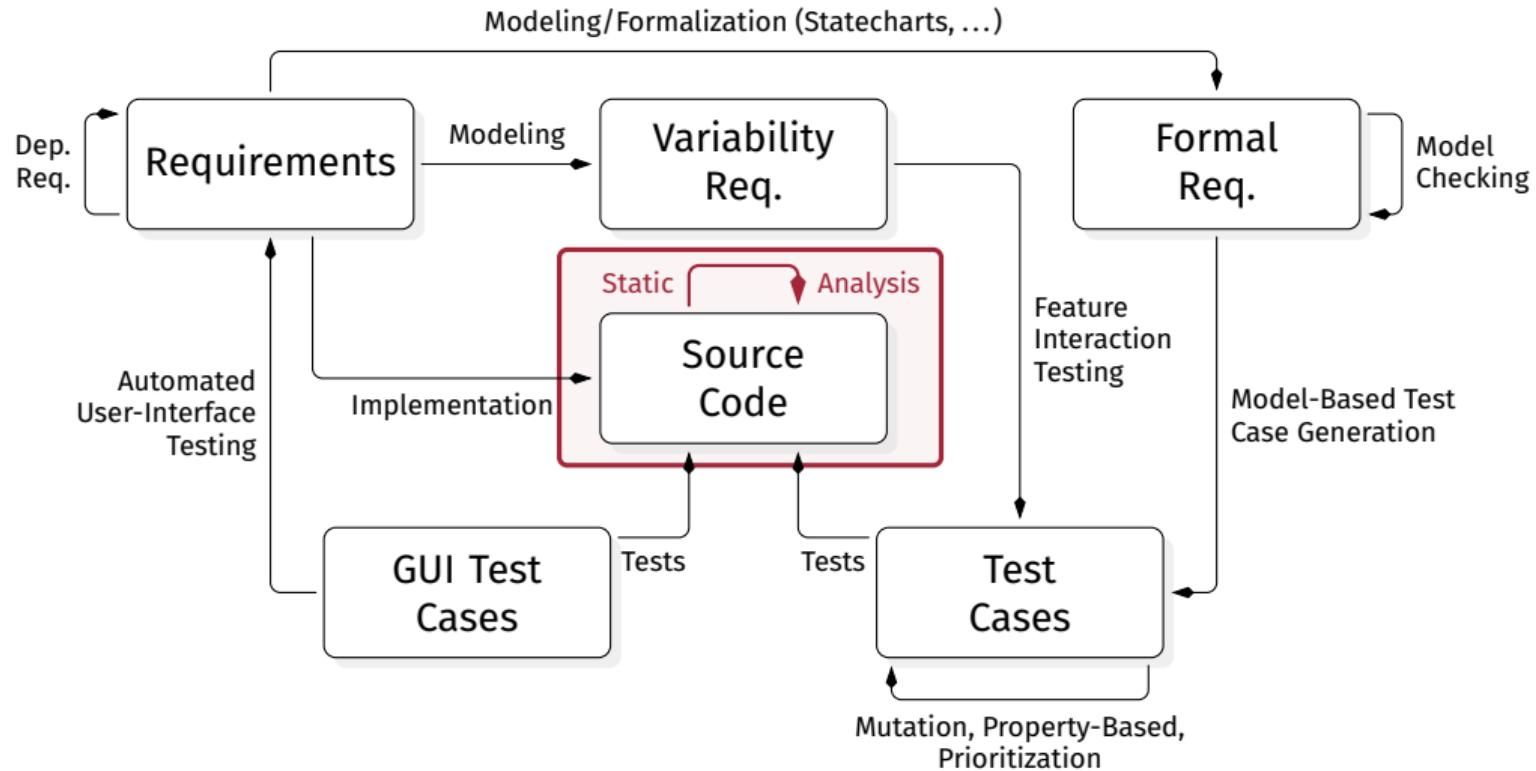
1. A first Overview

Embedding a Landscape

Embedding a Landscape



Embedding a Landscape







What is static code analysis?



What is static code analysis?



What is static code analysis?

Discover *syntactic/semantic properties* of programs
without running them. [RY20]



What is static code analysis?

Derivable purely on program syntax.
e.g., Line-Counts, Indentation, Parameter-Counts, ...

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without running them. [RY20]



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- Derivable purely on program syntax.
e.g., Line-Counts, Indentation, Parameter-Counts, ...
- Derivable from program semantics (behavior).
e.g., Possible Variable Values, Termination, ...

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Reason on *all* possible executions.



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- Find bugs or vulnerabilities



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- Reason on *all* possible executions.



Why do static analysis?

- Find bugs or vulnerabilities
- Prove correctness
- Find and apply optimizations
- Follow coding guidelines / style guides
- Refactoring support
- ...
(it is fun!)

Let's find some bugs!

Let's find some bugs!



Let's test!

Let's find some bugs!

Dynamic

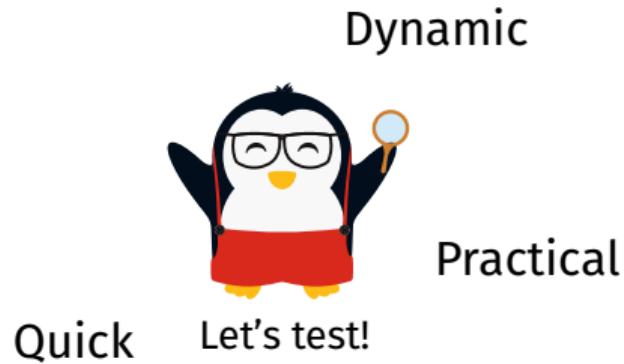


Let's test!

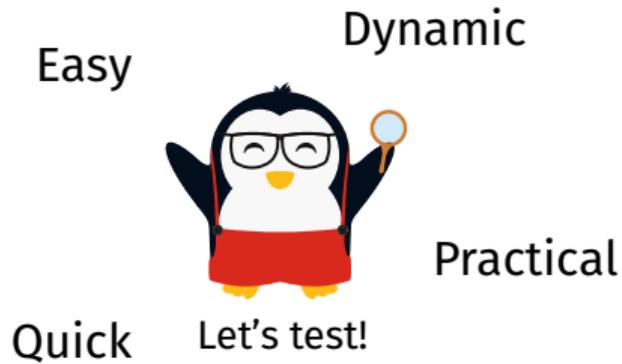
Let's find some bugs!



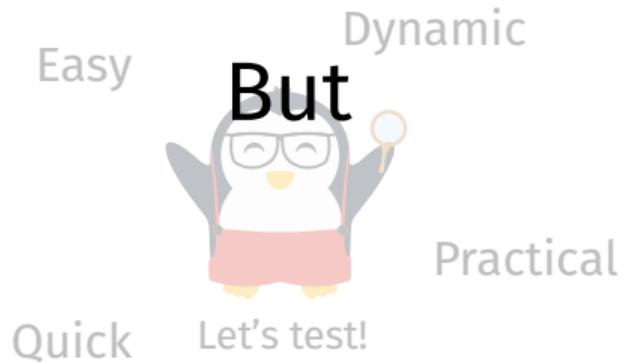
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Let's find some bugs!



Let's find some bugs!

Easy Dynamic
Quick Practical
But,
Tests are
Unsound!

Let's find some bugs!



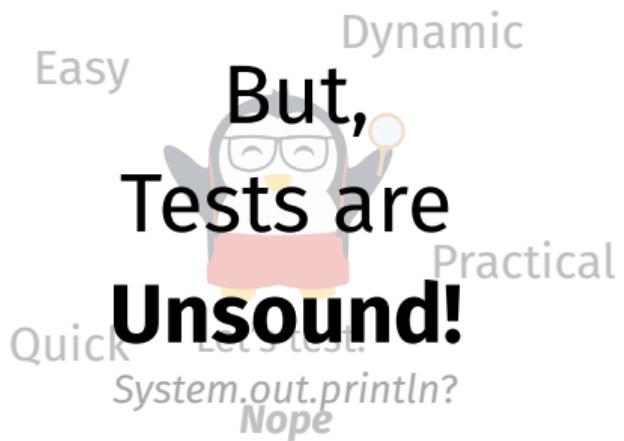
Easy Dynamic
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System.out.println?

Let's find some bugs!

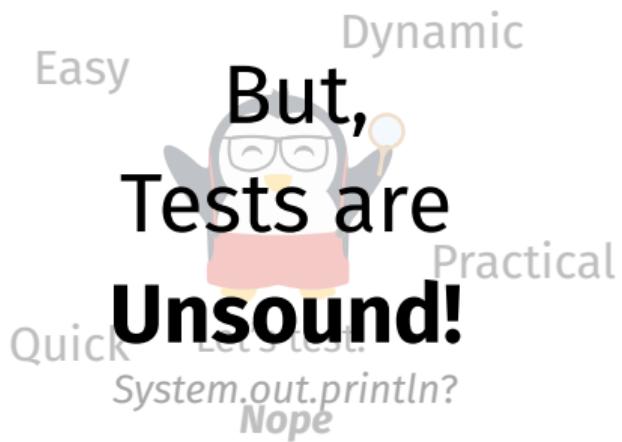


Easy Dynamic
Quick Practical
But,
Tests are
Unsound!
Let's test.
System.out.println?
Nope

Let's find some bugs!



Let's find some bugs!



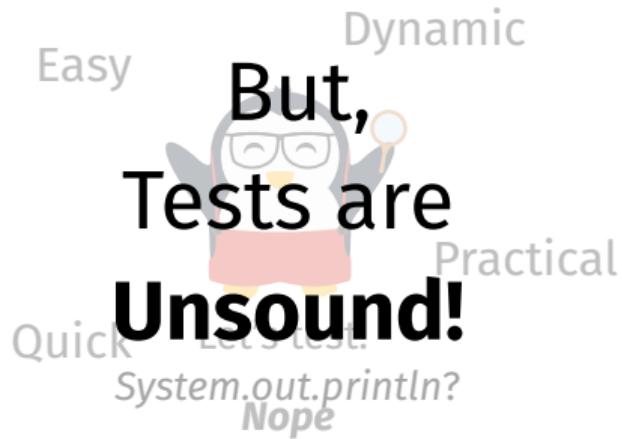
“Program testing can be used to show the presence of bugs, but never to show their absence!”

Dijkstra [Dij69]

Let's find some bugs!



Edsger W. Dijkstra (1930–2002)
Communications of the ACM



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A First Look

A First Look

They take **Input**



A First Look

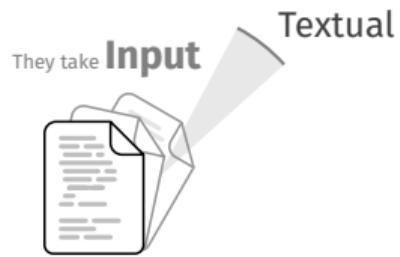
And use **Perspectives** (often combined)

They take **Input**



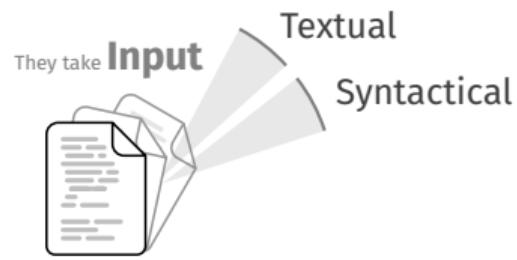
A First Look

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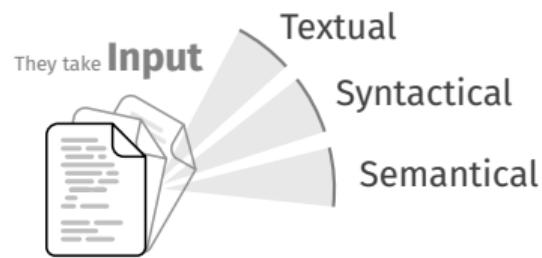
A First Look

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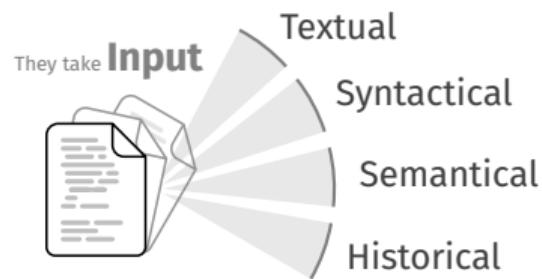
A First Look

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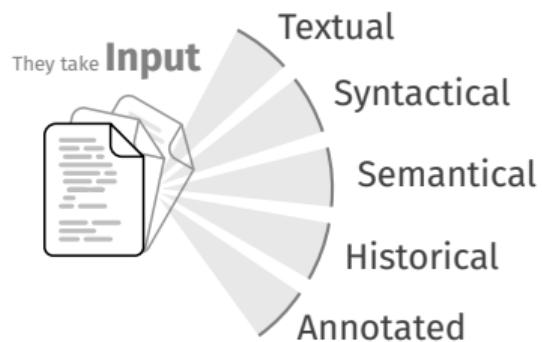
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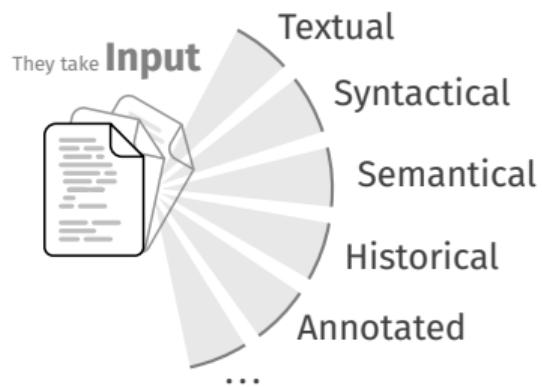
A First Look

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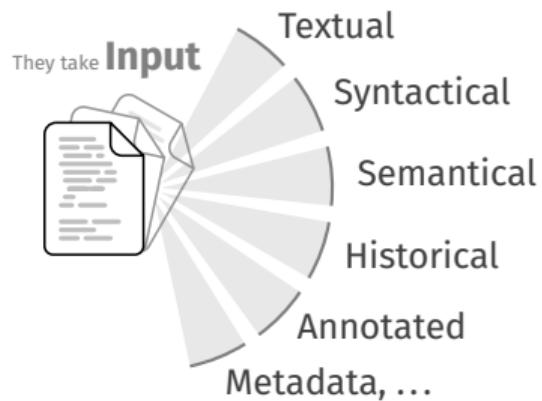
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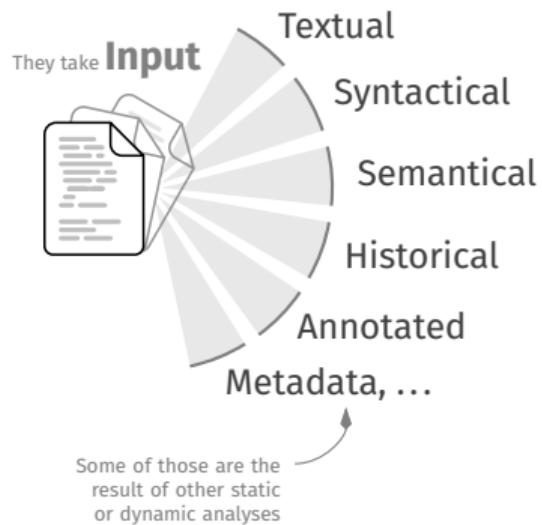
A First Look

And use **Perspectives** (often combined)

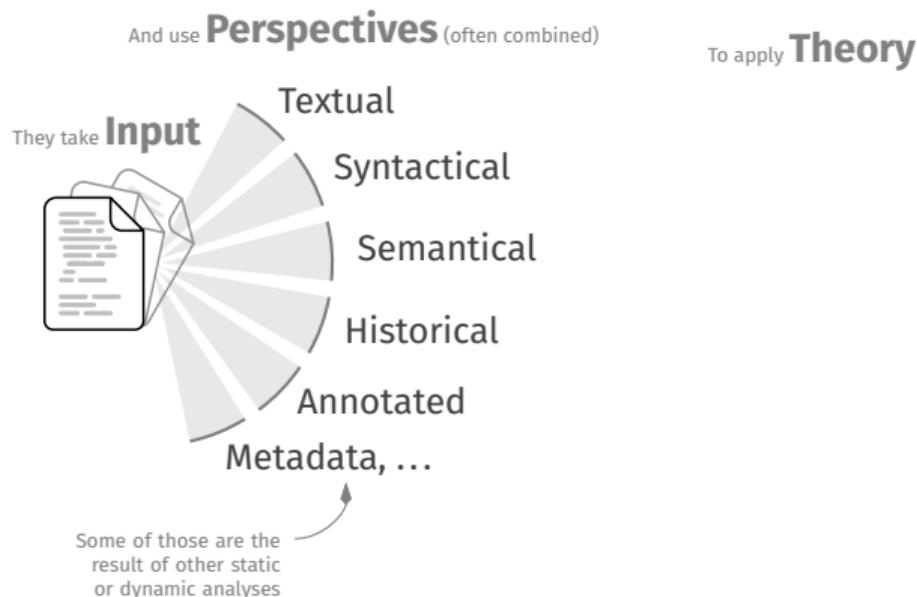


A First Look

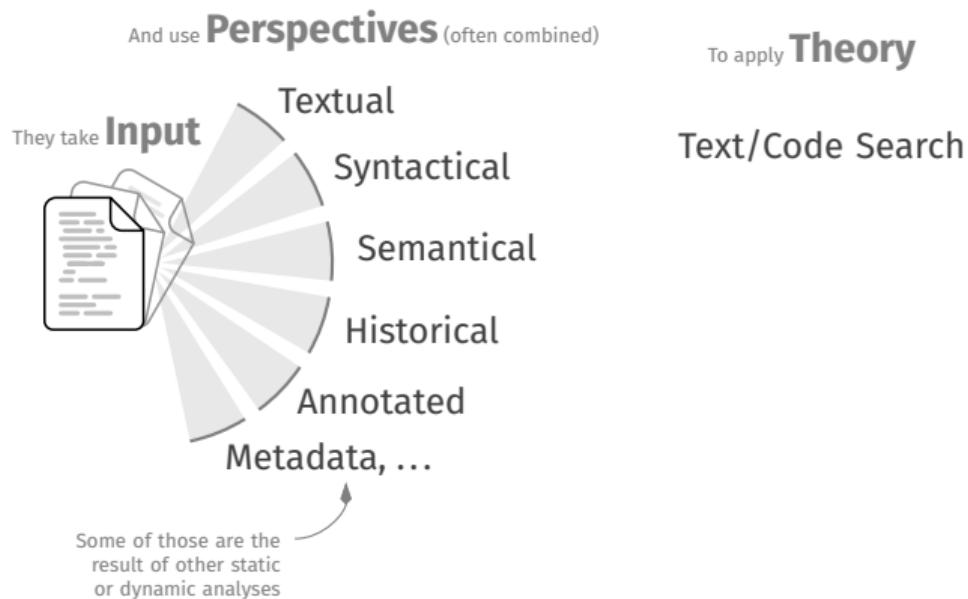
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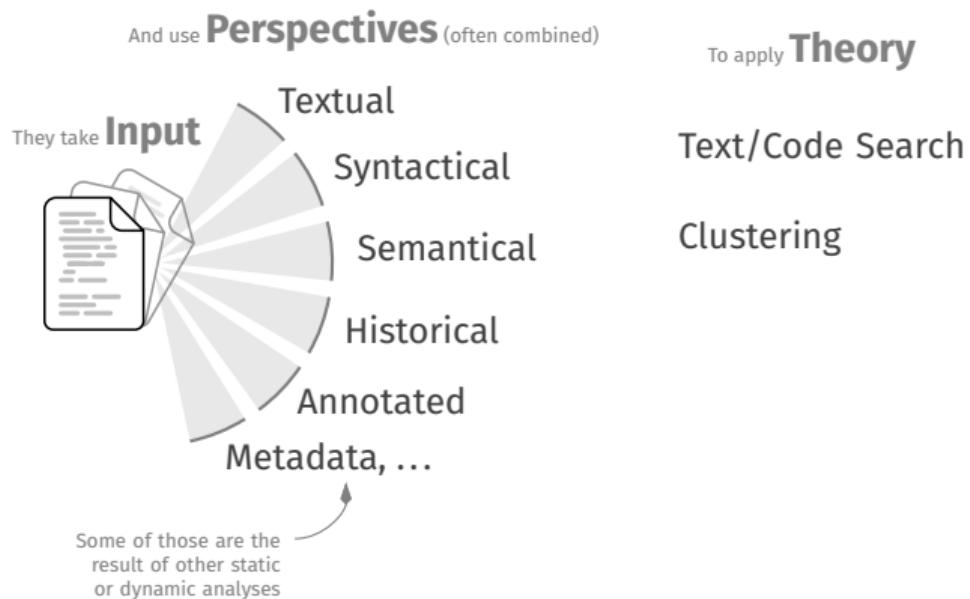
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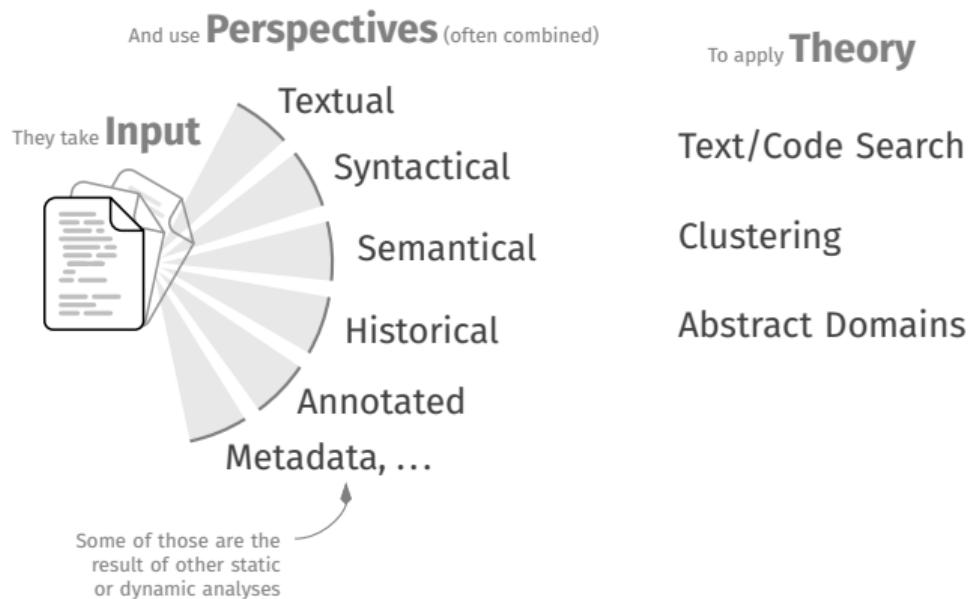
A First Look



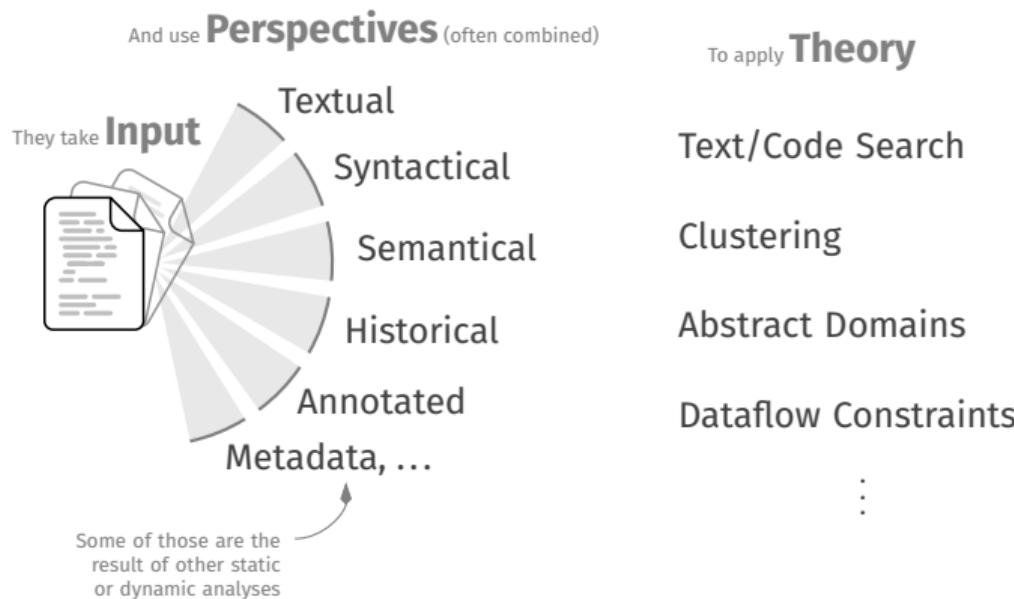
A First Look



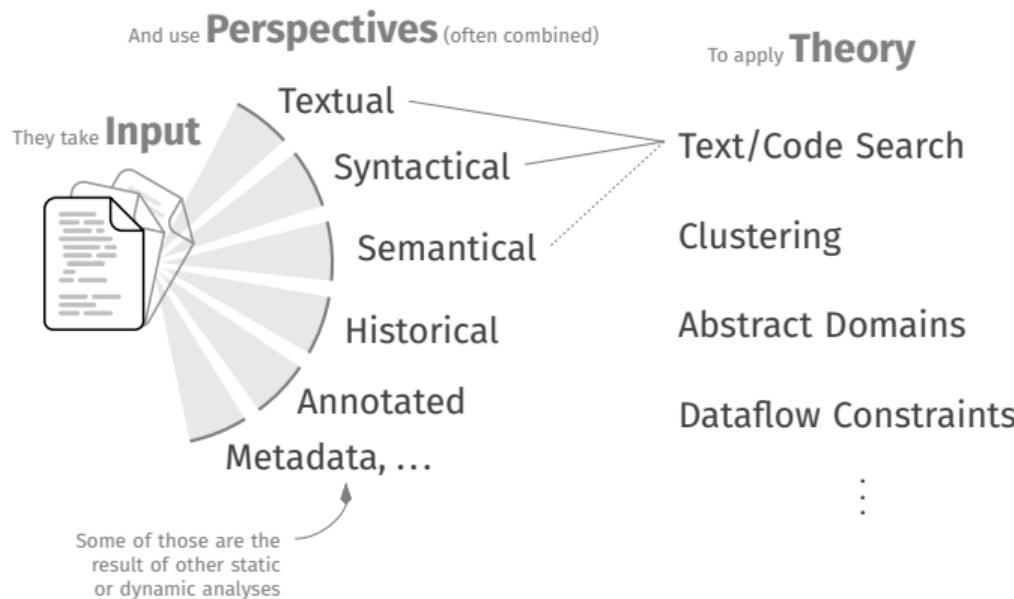
A First Look



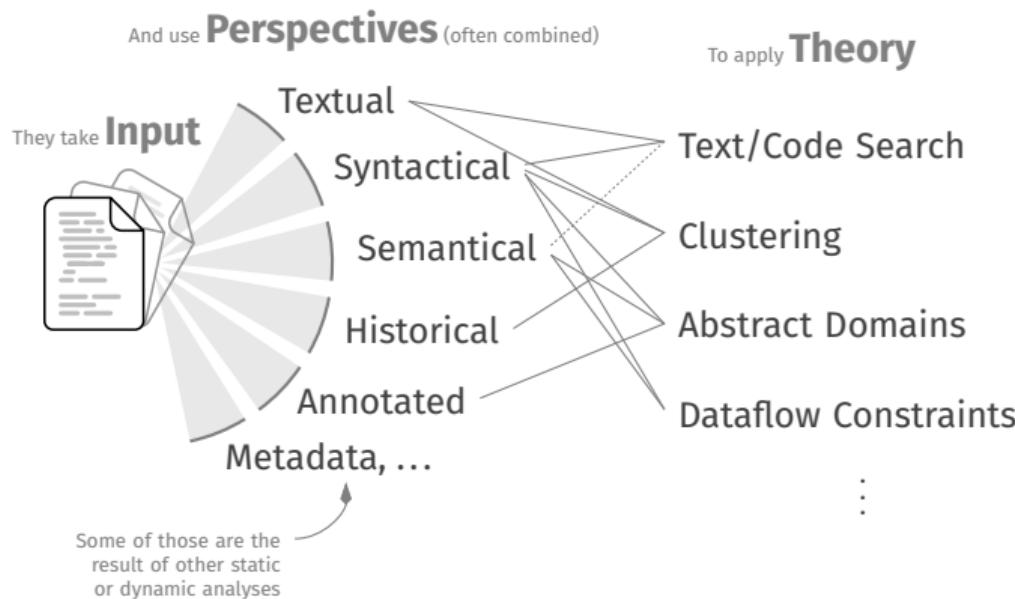
A First Look



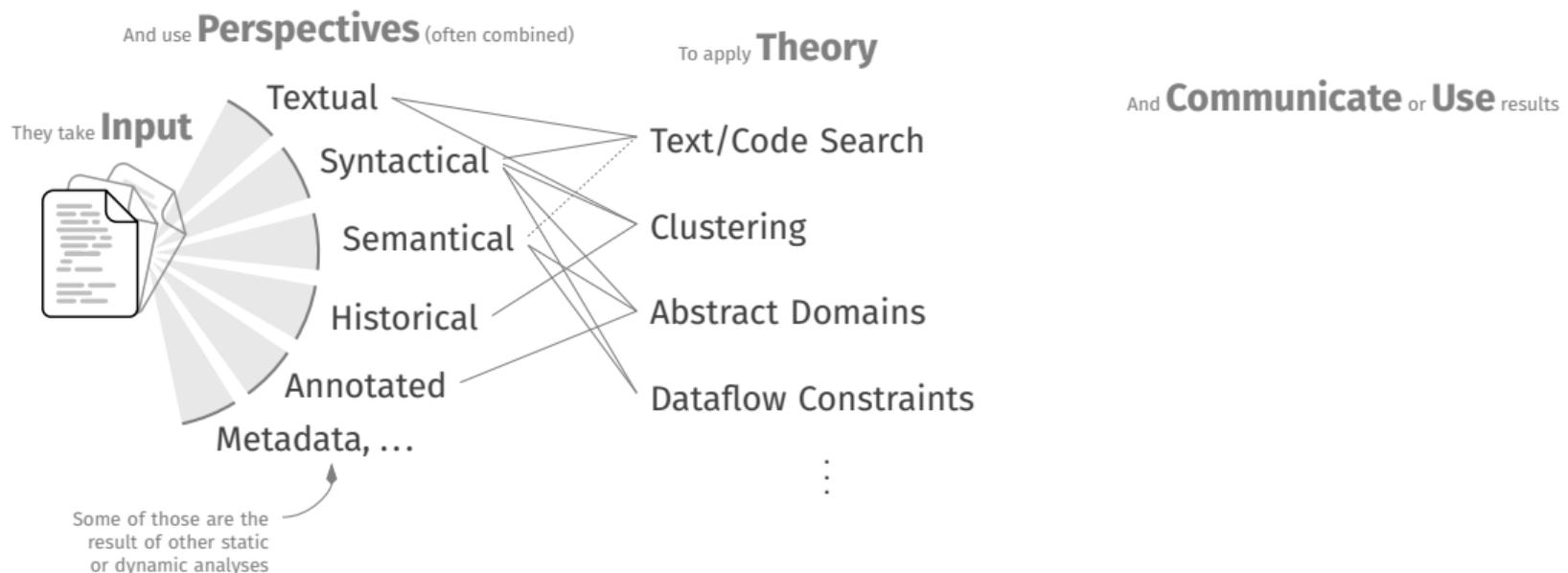
A First Look



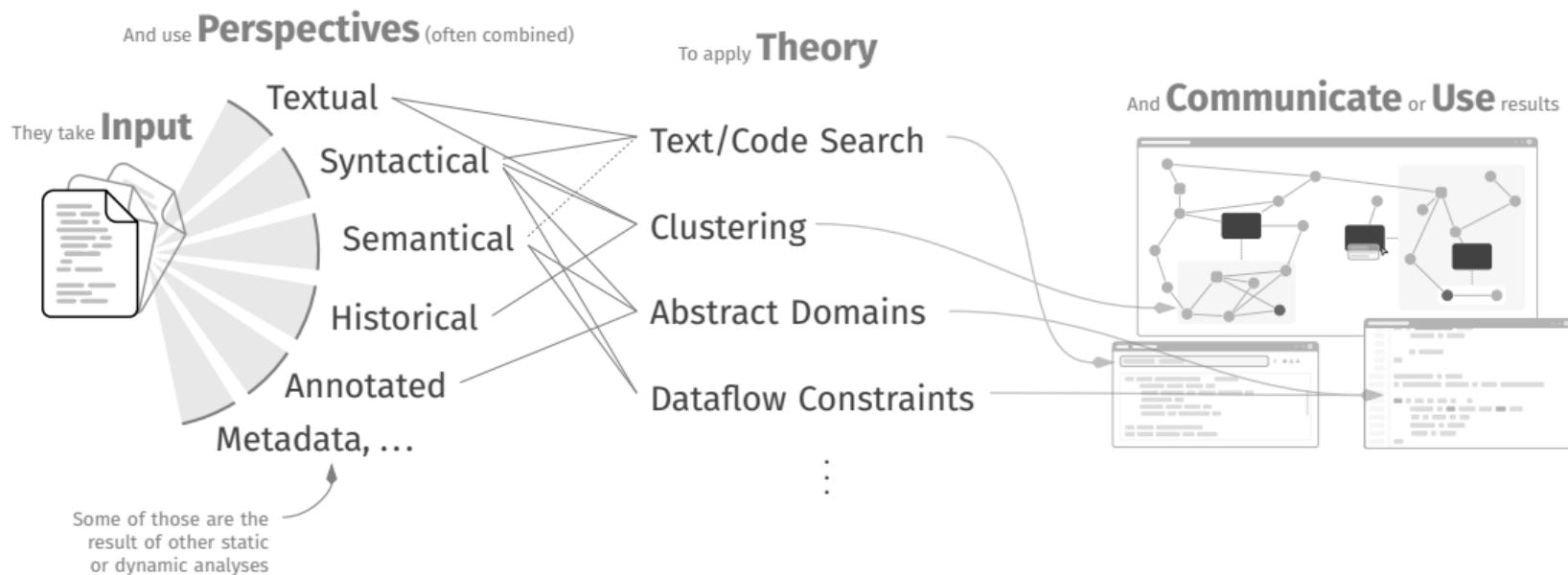
A First Look



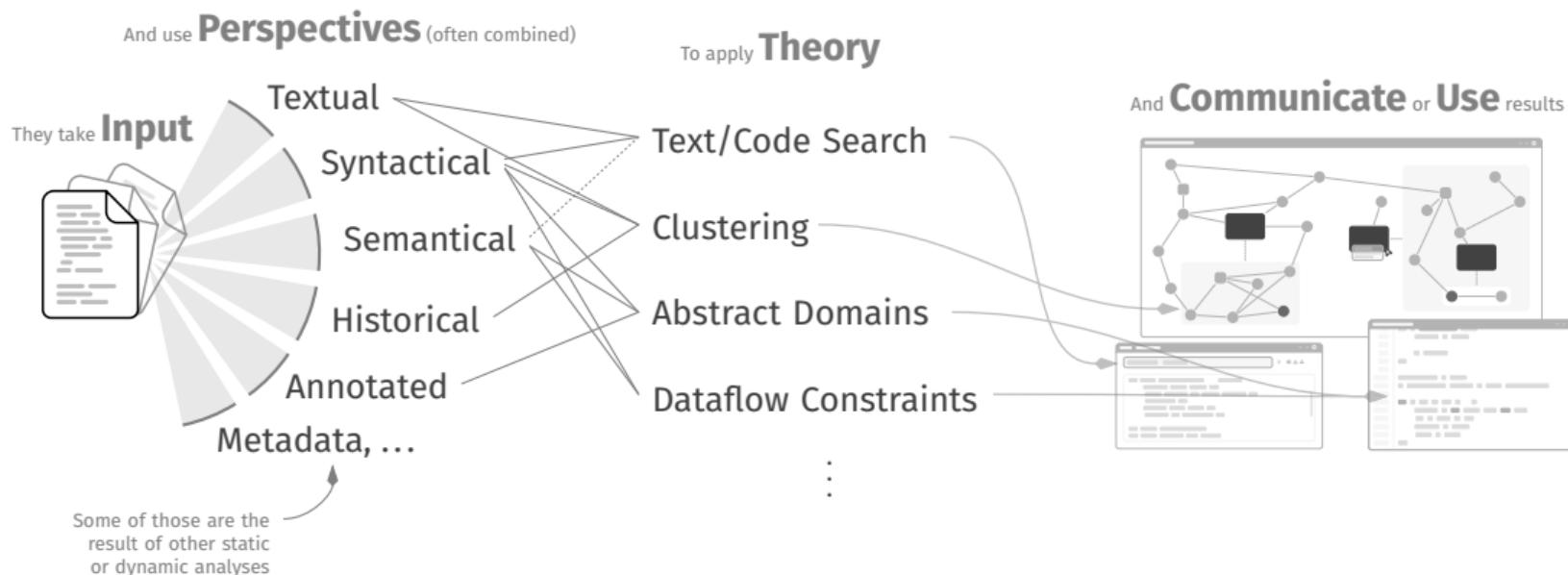
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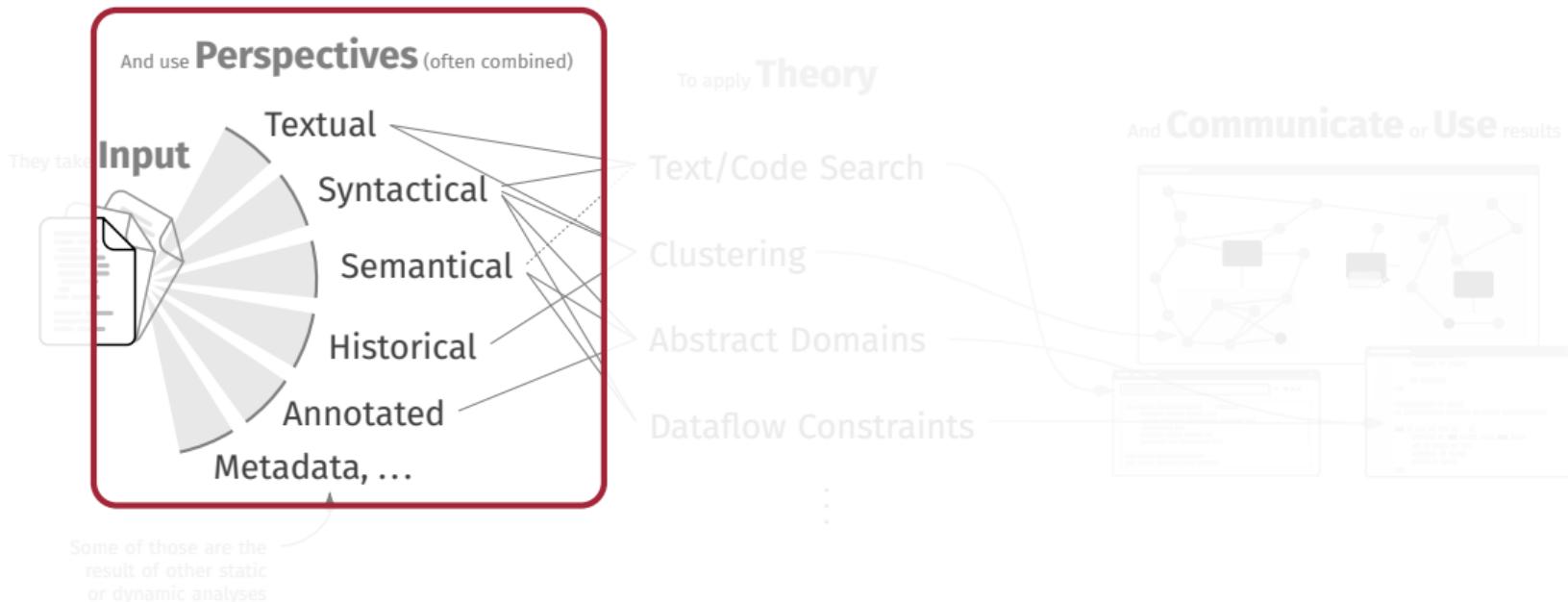
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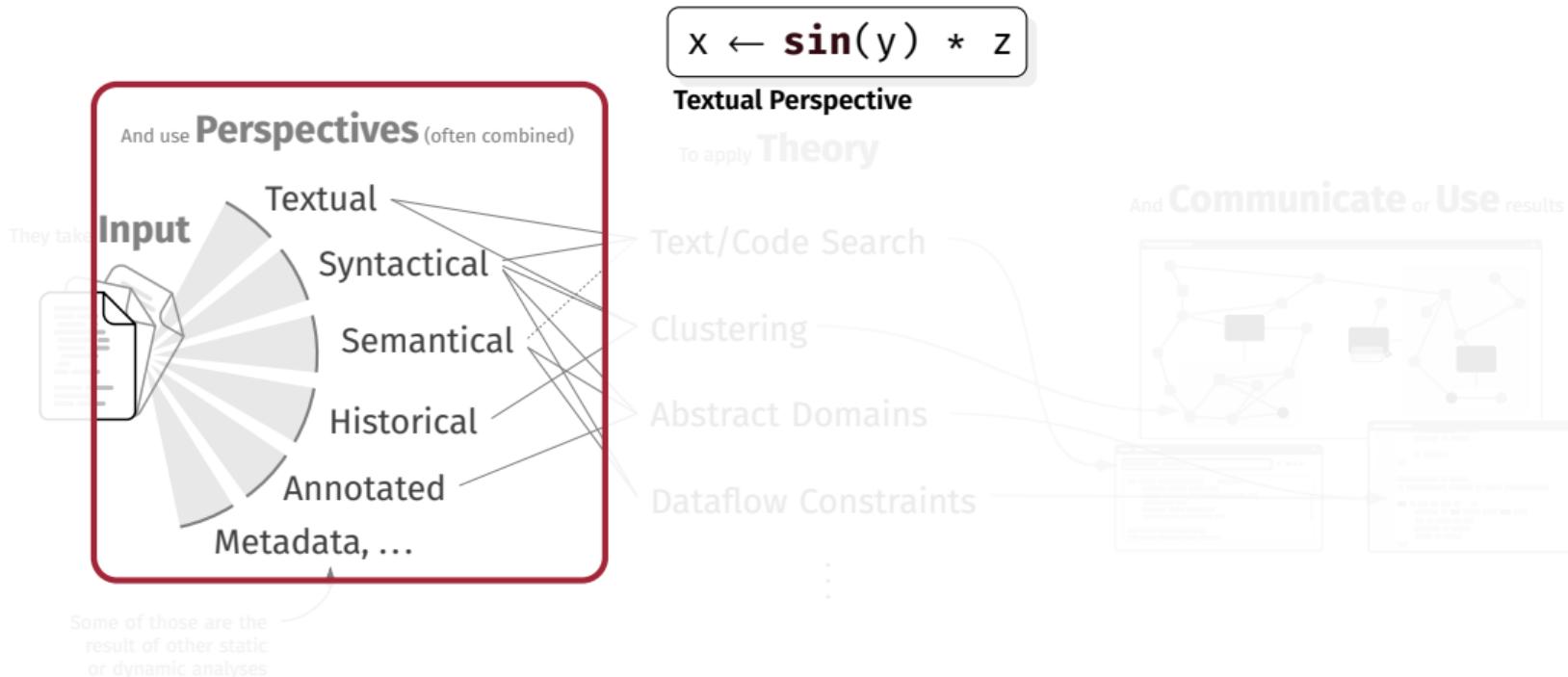
Perspectives



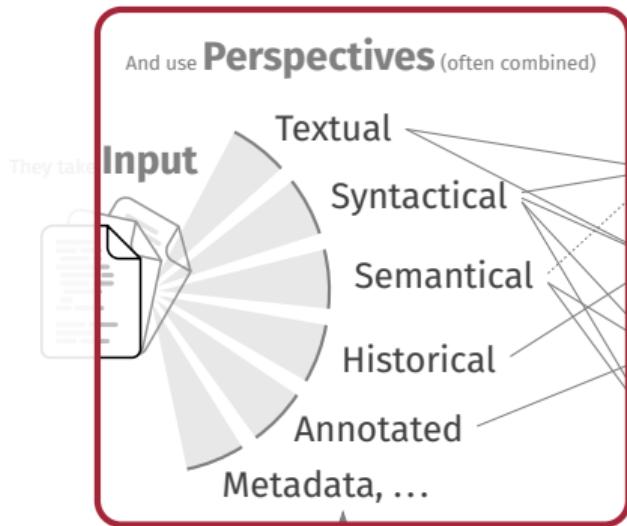
Perspectives



Perspectives



Perspectives



$x \leftarrow \sin(y) * z$

Textual Perspective

To apply Textual Perspective to the code above, we can use a parser to extract tokens and their positions. This results in a parse tree where each node represents a token and its context.

$$\begin{array}{c} x \\ \leftarrow \\ * \\ \sin \\ - \\ y \\ z \end{array}$$

Syntactical Perspective (AST)

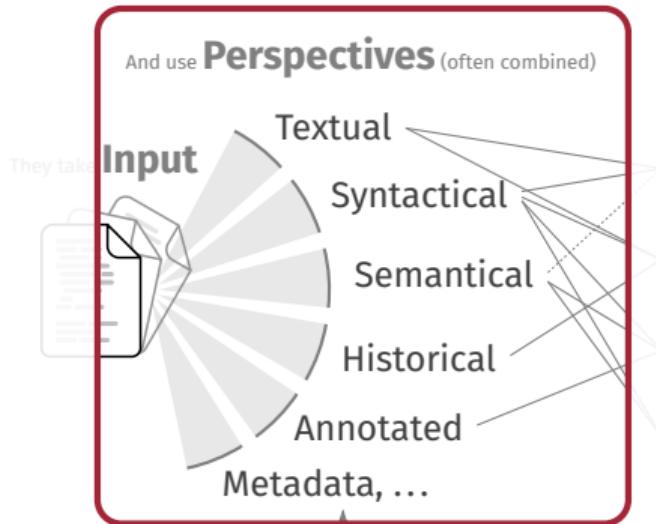
Abstract Domains

Dataflow Constraints

and Communicate or Use results



Perspectives



Some of those are the result of other static or dynamic analyses

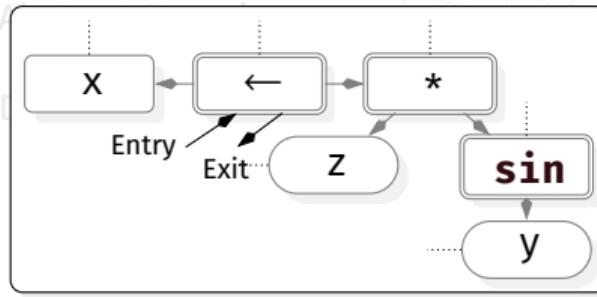
$x \leftarrow \sin(y) * z$

Textual Perspective

To apply Text/Code analysis
Text/Code analysis
Cluster analysis
...
and Communicate or Use results

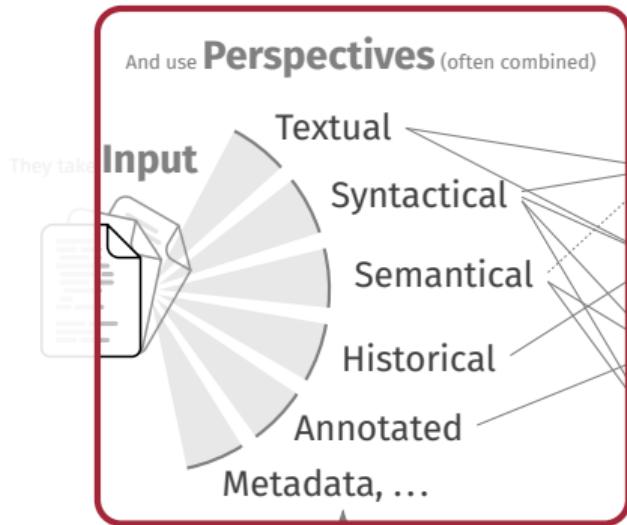
$$x \leftarrow \sin - y * z$$

Syntactical Perspective (AST)



Semantical Perspective (CFG & DFG)

Perspectives



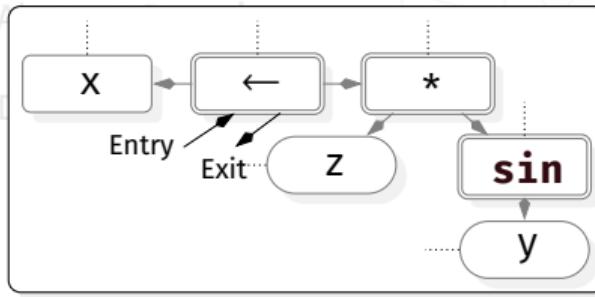
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Textual Perspective

$\begin{array}{c} x \\ \leftarrow \\ * \\ \quad \quad \quad \sin - y \\ \quad \quad \quad z \end{array}$

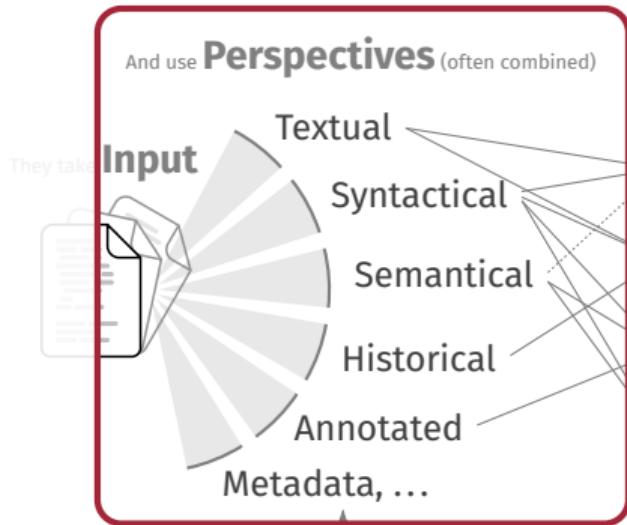
Syntactical Perspective (AST)



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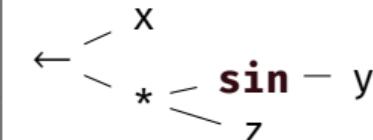
Perspectives



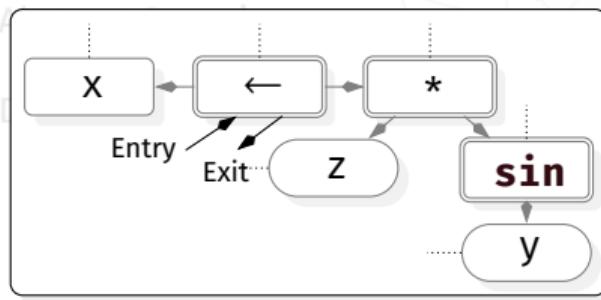
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Textual Perspective



Syntactical Perspective (AST)



Semantical Perspective (CFG & DFG)

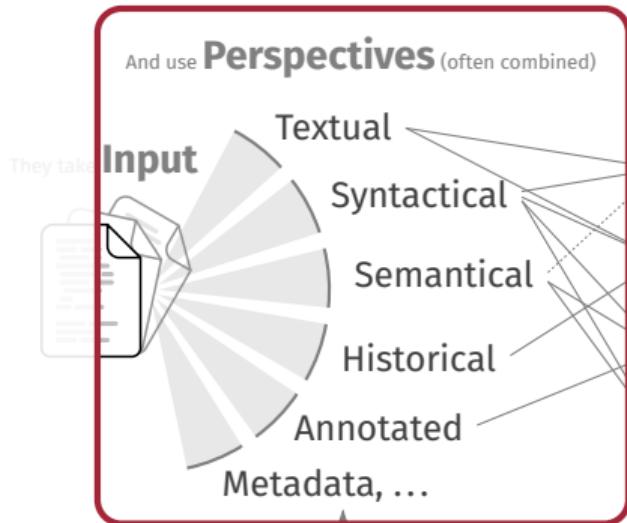
- Initial Commit
- Added Functionality
- Refactored
- Bug Fix
- Optimized Nothing

Historical Perspective

Caused CVE 2025-12345
 $x \leftarrow \sin(y)$

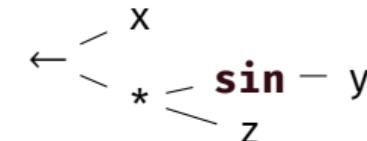
Annotated Perspective

Perspectives

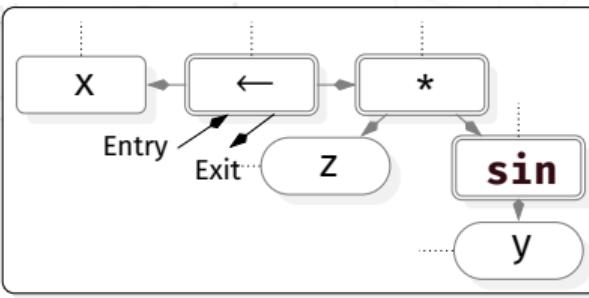


$x \leftarrow \sin(y) * z$

Textual Perspective



Syntactical Perspective (AST)



Semantical Perspective (CFG & DFG)

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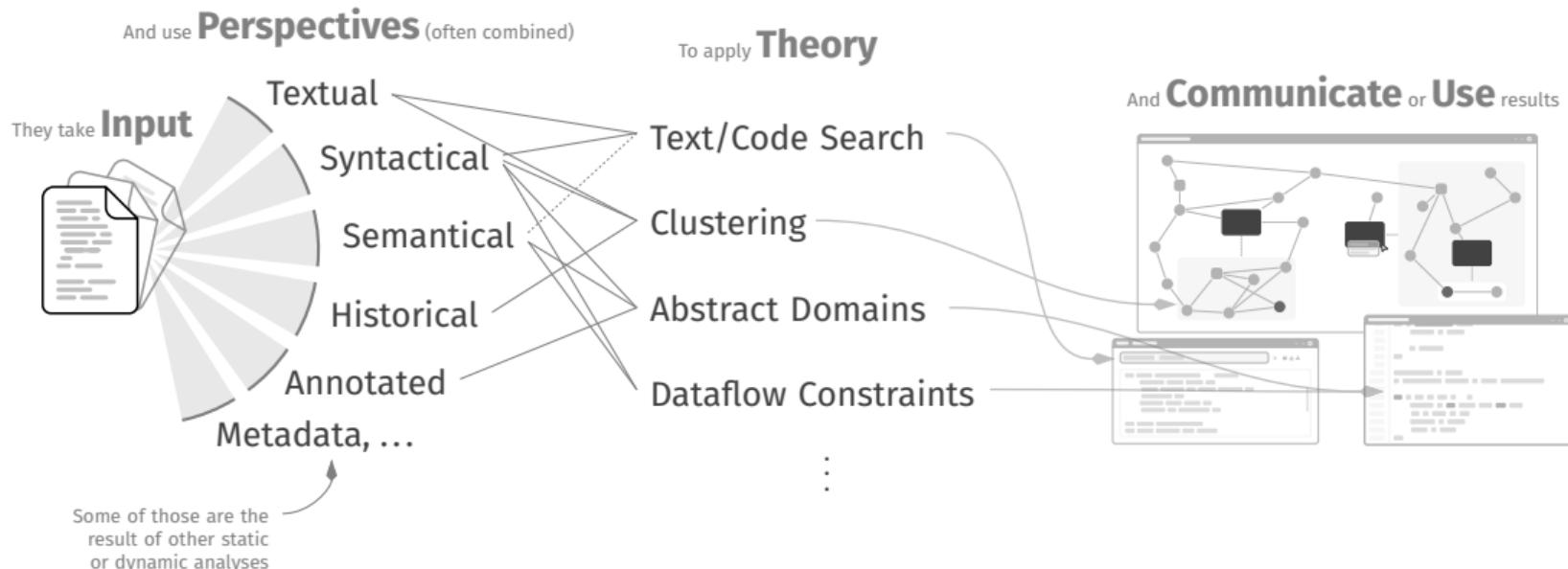
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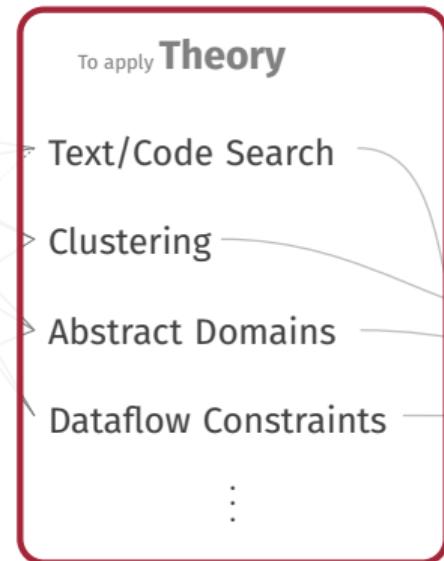
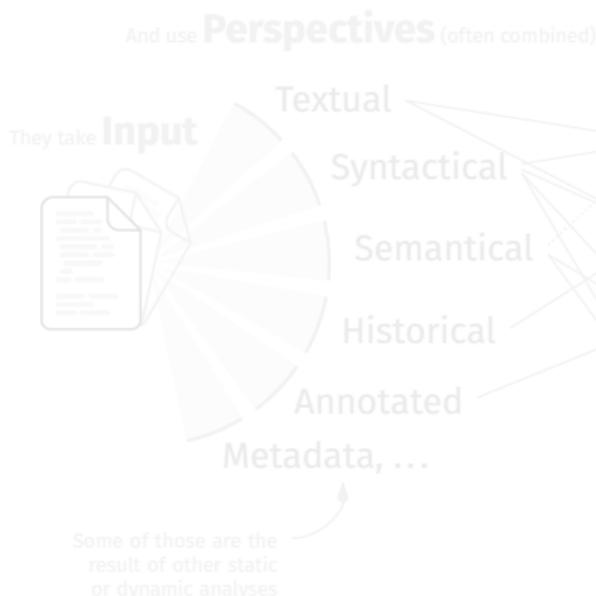
Author: Jane Doe
Code Review: Passed
...

Metadata Perspective

Theory



Theory



Theory

```
(assignment_expression  
  left: (member_expression  
    object: (call_expression)  
  ))
```

Searching for Patterns



Semantical
Historical
Annotated
Metadata, ...

Some of those are the
result of other static
or dynamic analyses

Theory

To apply

- > Text/Code Search
- > Clustering
- > Abstract Domains
- > Dataflow Constraints
- ⋮

And Communicate or Use results



Theory

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  left: (member_expression  
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```

Searching for Patterns

```
r <- read.csv("data.csv")      load  
r <- filter(r, value > 10)    transf.  
plot(r$time, r$value)          vis.  
lines(r$time, r$score)
```

result of other static
or dynamic analyses

Clustering

To apply **Theory**

- > Text/Code Search
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And **Communicate or Use** results



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To apply **Theory**

- > Text/Code Search
- > Clustering
- > Abstract Domains
- > Dataflow Constraints
- ⋮

$$\top = [-\infty .. \infty]$$

$$\perp = \emptyset$$

$$\bigcup_k [\ell_k .. h_k] = [\min(\ell_k) .. \max(h_k)]$$
$$\bigcap_k [\ell_k .. h_k] = [\max(\ell_k) .. \min(h_k)]$$

Abstract Domains

Theory

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Clustering

To apply **Theory**

- > Text/Code Search
- > Clustering
- > Abstract Domains
- > Dataflow Constraints
- ⋮

$$\begin{aligned} T &= [-\infty .. \infty] \\ x &\leftarrow 2 * \text{rnd}(0, 1) \quad x \in [0, 2] \\ y &\leftarrow x + 1 \quad [min(\ell_k) .. max(h_k)] \quad y \in [1, 3] \\ z &\leftarrow y + \text{abs}(u) \quad z \in [1, \infty] \\ \bigcap_k [\ell_k .. h_k] &= [max(\ell_k) .. min(h_k)] \end{aligned}$$

Abstract Domains

Theory

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- ⋮

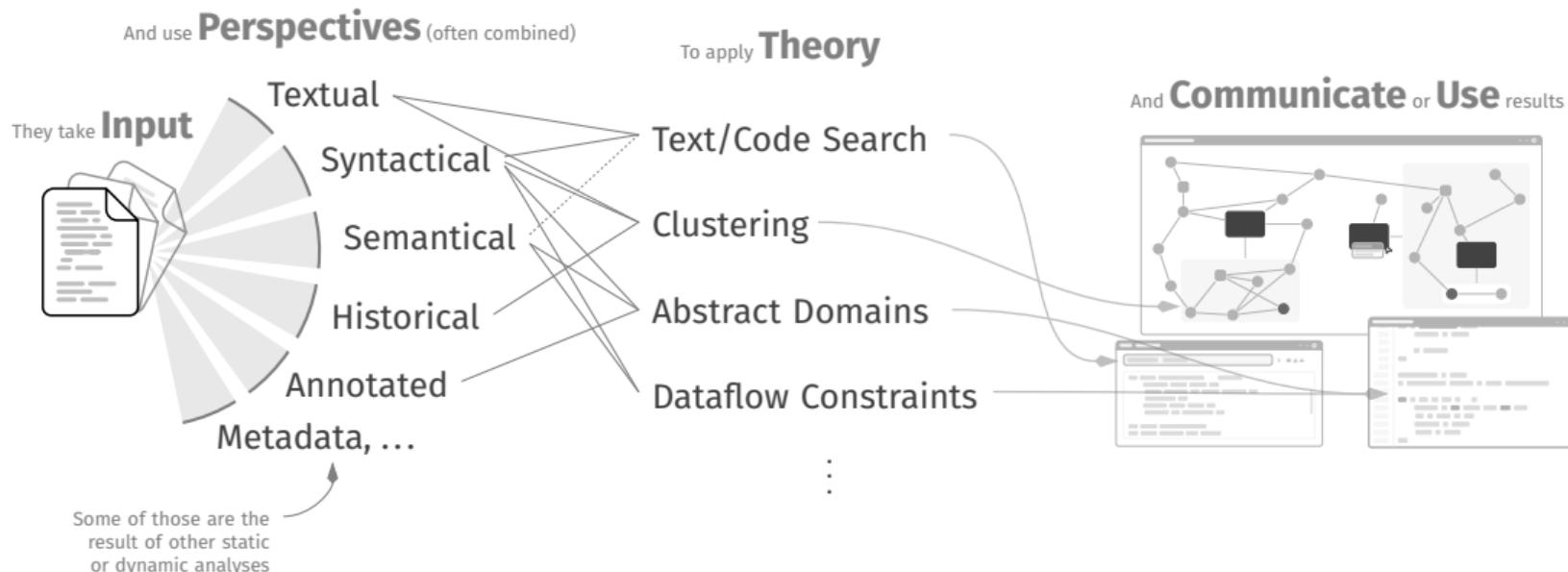
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Abstract Domains

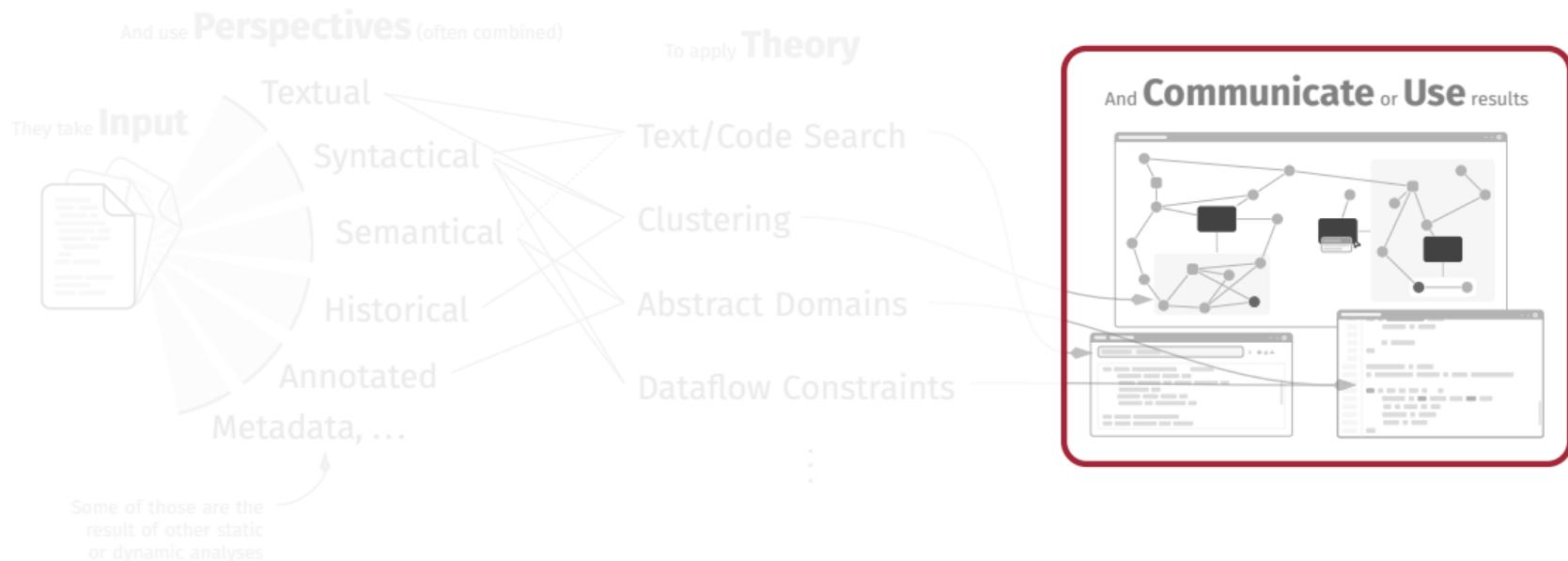
$$\begin{aligned} \mathbf{In}_n &= (\mathbf{Out}_n - \mathbf{Kill}_n) \cup \mathbf{Gen}_n \\ \mathbf{Out}_n &= \begin{cases} \mathbf{BI} & n \text{ is End} \\ \bigcup_{m \in \text{succ}(n)} \mathbf{In}_m & \text{else} \end{cases} \end{aligned}$$

Dataflow Constraints

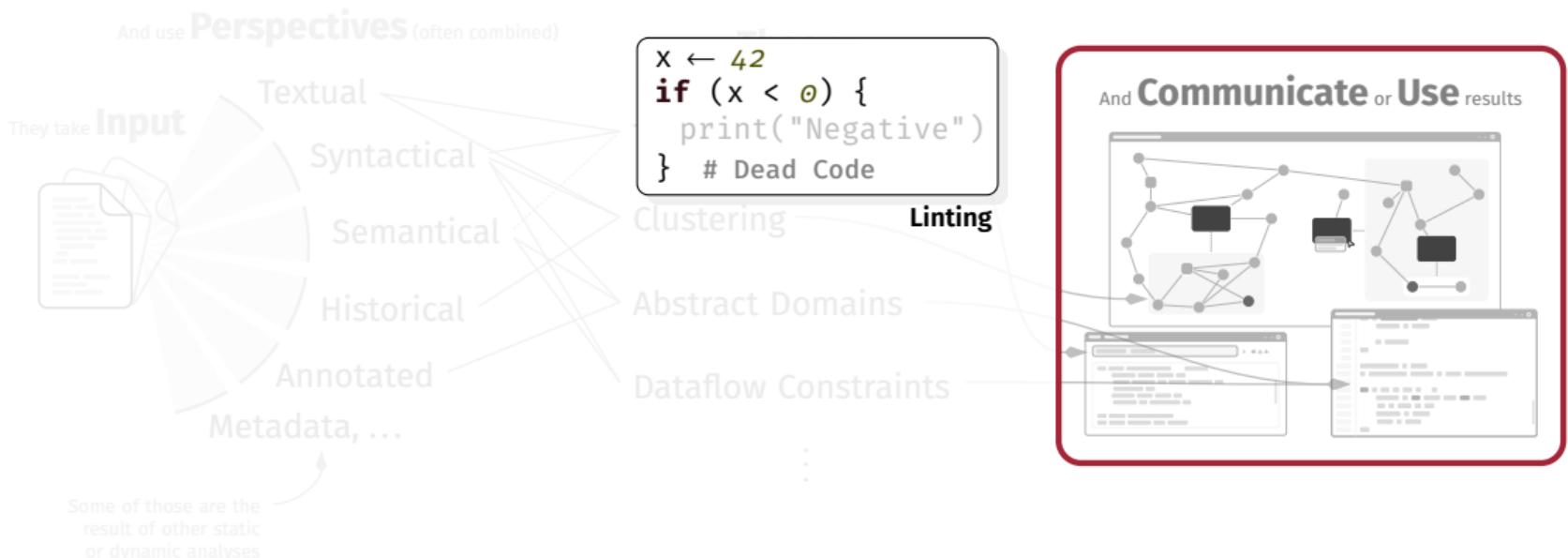
Application



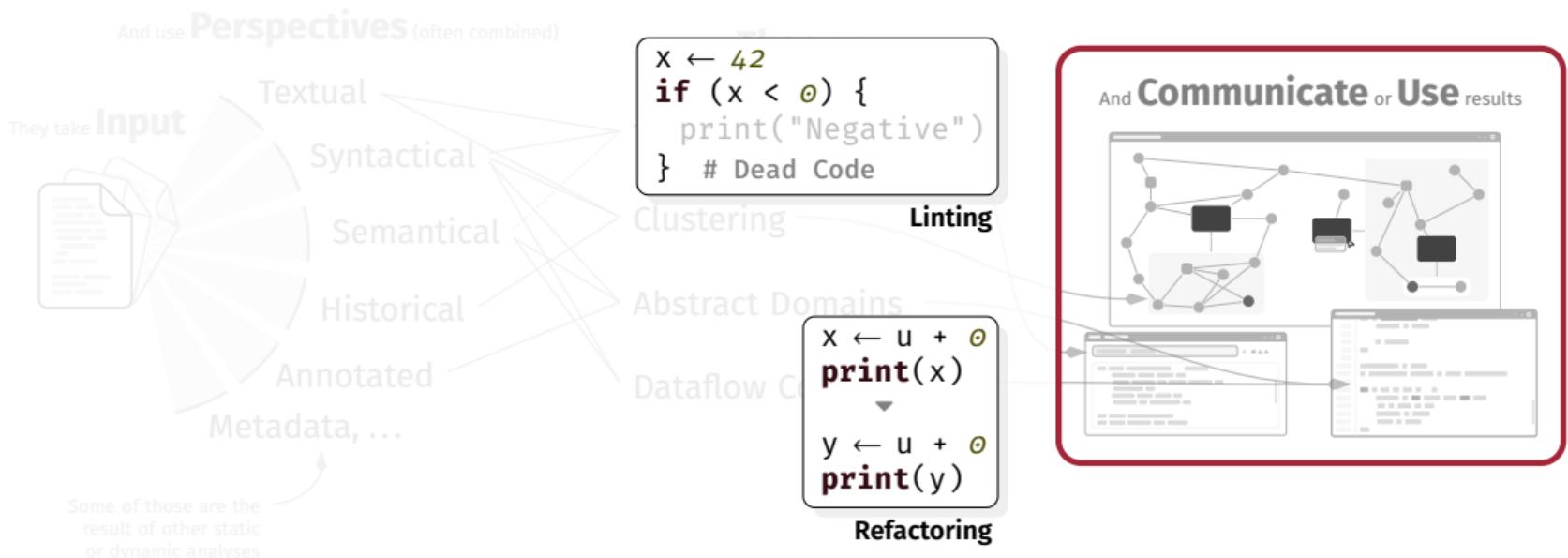
Application



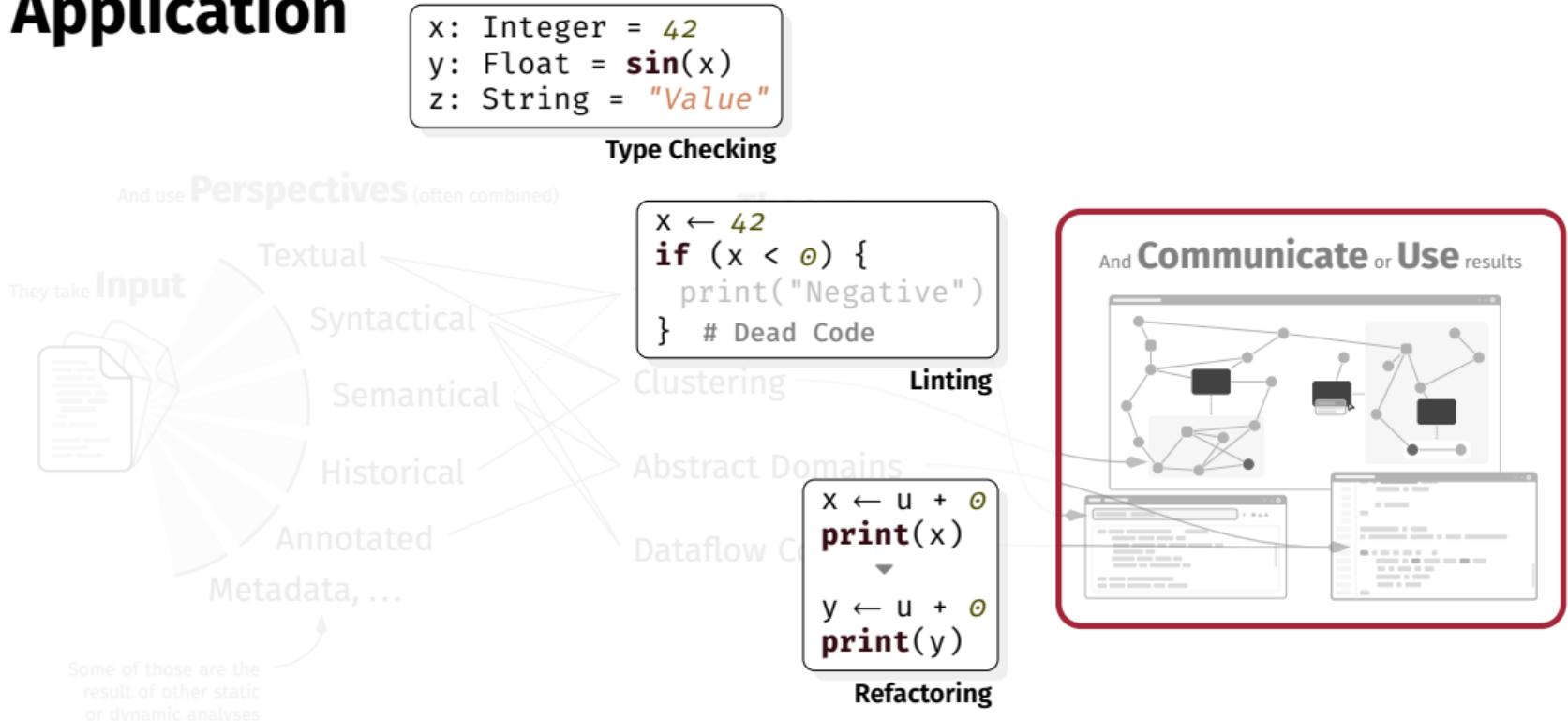
Application



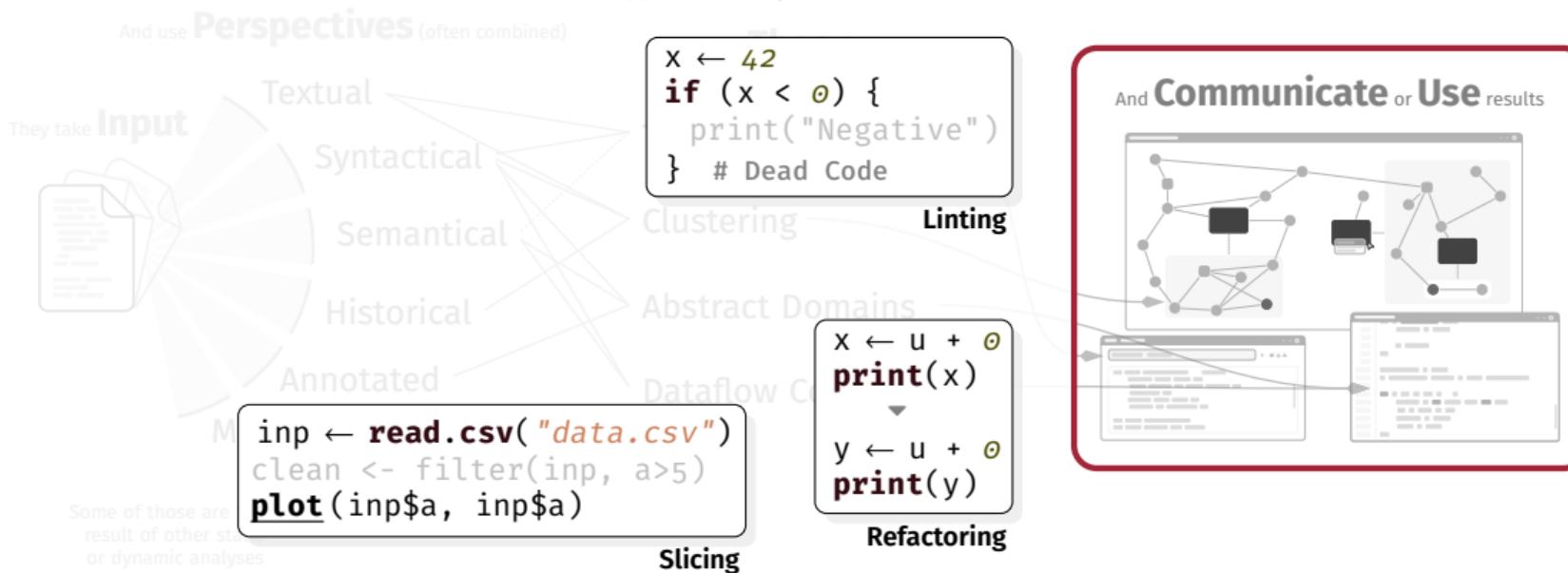
Application



Application



Application



Application

They take Input



And use Perspectives (often combined)

```
for (i in 1:n) {  
    sum ← sum + i  
}  
  
sum ← n*(n+1)/2
```

Optimization

Type Checking

```
x: Integer = 42  
y: Float = sin(x)  
z: String = "Value"
```

```
x ← 42  
if (x < 0) {  
    print("Negative")  
} # Dead Code
```

Linting

```
inp ← read.csv("data.csv")  
clean <- filter(inp, a>5)  
plot(inp$a, inp$a)
```

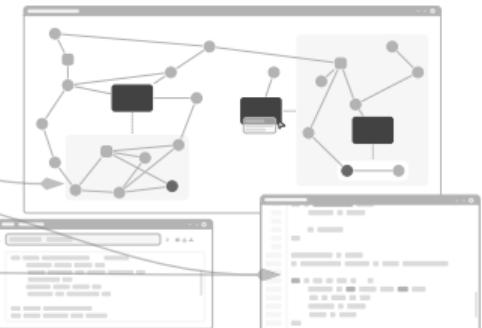
Slicing

```
x ← u + 0  
print(x)  
  
y ← u + 0  
print(y)
```

Refactoring

Some of those are
result of other static
or dynamic analyses

And Communicate or Use results



Application

```
x: Integer = 42  
y: Float = sin(x)  
z: String = "Value"
```

Type Checking

And use **Perspectives** (often combined)

```
assert(x >= 0)  
a ← angleCmp(x)  
  
verify(  
    0 <= a &&  
    a <= 40  
)
```

Verification

```
for (i in 1:n) {  
    sum ← sum + i  
}  
  
sum ← n*(n+1)/2
```

Optimization

```
x ← 42  
if (x < 0) {  
    print("Negative")  
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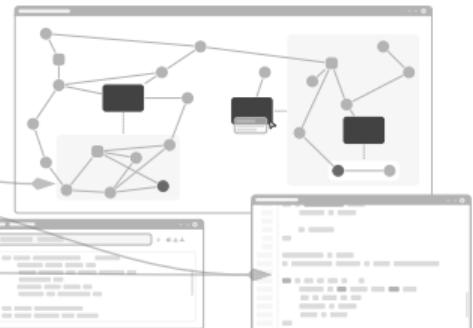
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2. Linting Origins

A User-Driven History: Linting

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 - Identification of dead code
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Which linters do you know?
⇒ Part 3



A Word on “Linting”

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Linting is often used as a generic term!

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In the following, we explore some common linting tasks.

Style Checks

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Check compliance with coding style guidelines

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 - Missing *switch* cases (forcing *default*)
 - Require non-empty *catch* blocks



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Style guides can be, language, organization,
domain, or even project specific!



Good Code, Bad Code

Good Code, Bad Code

```
int timeToReadBook = (220 * 10) / 60;
```

java

Good Code, Bad Code

```
int timeToReadBook = (220 * 10) / 60;  
                         ↘ Apples? Oranges?
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Good Code, Bad Code

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int timeToReadBook = (220 * 10) / 60;  
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java

```
final int PAGES = 220;  
final int MINUTES_PER_PAGE = 10;  
final int MINUTES_PER_HOUR = 60;
```

java

```
int timeToReadBook = (PAGES * MINUTES_PER_PAGE) /  
                     MINUTES_PER_HOUR;
```

And Besides Synthetical Examples?

<http://support.apple.com/kb/HT6147>

And Besides Synthetical Examples?

```
libsecurity_ssl/lib/sslKeyExchange.c

574 static OSStatus
575 SSLVerifySignedServerKeyExchange(SSLContext *ctx, bool isRsa, SSLBuffer signedParams,
576                                     uint8_t *signature, UInt16 signatureLen)
577 {
// ...
620     if ((err = SSLFreeBuffer(&hashCtx)) != 0)
621         goto fail;
622
623     if ((err = ReadyHash(&SSLHashSHA1, &hashCtx)) != 0)
624         goto fail;
625     if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
626         goto fail;
627     if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
628         goto fail;
629     if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
630         goto fail;
631         goto fail;
632     if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
633         goto fail;
// ...
647 fail:
648     SSLFreeBuffer(&signedHashes);
649     SSLFreeBuffer(&hashCtx);
650     return err;
651 }
652 }
```

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631     goto fail;  Wellp!
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591     if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
592         goto fail; ↗ Well!
593     if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
594         goto fail;
595
596     // ...
597 fail:
598     SSLFreeBuffer(&signedHashes);
599     SSLFreeBuffer(&hashCtx);
600     return err; ↗ Now, err can be 0, signaling a valid signature!
601 }
602 }
```

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Style Checks: Summary

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- How to do style checks?

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yaml

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```
rules:                                     yaml
  - id: add-if-braces
    pattern: if ($COND) $BODY
    constraints: $BODY: not:
      kind: block
    rewrite: if ($COND) { $BODY }
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- Usually, they are heavily configurable to fit project needs
- Likewise, they are usually only syntactic, without semantic info (although many offer more features)
- Examples: `checkstyle`, `pylint`, `ESLint Stylistic`, ...

Please consider using `.git-blame-ignore-revs`.

Unconventional Patterns and Bugs

Unconventional Patterns and Bugs

```
for (int i=1; i<=3; i++);
    f(i);
```

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Unconventional Patterns and Bugs

- Various Categories:

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Unconventional Patterns and Bugs

- Various Categories:
 - Single-Threaded corr.

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Error Mining

See also:

- [HvP04] David Hovemeyer and William Pugh. Finding bugs is easy (Association for Computing Machinery, 2004)
- [Bre12] Alexander Breckel. Error mining: Bug detection through comparison with large code databases (MSR, 2012)

Error Mining

```
for(j = 0; j < -n; j++) array[i] = j;
```

```
for(i = 0; i < k; i++) arr[i] = i;
```

See also:

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Error Mining

```
for(j = 0; j < -n; j++) array[i] = j;  
      ↓    ↓    ↓    ↓  
      i = j -n = k array = arr  
  
for(i = 0; i < k; i++) arr[i] = i;
```

See also:

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for(i = 0; i < k; i++) arr[i] = i;
```

- We try to find code that has been *almost* written like this!

See also:

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Error Mining

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for(j = 0; j < -n; j++) array[i] = j;  
      ↓    ↓    ↓    ↓  
      i = j -n = k array = arr  
  
for(i = 0; i < k; i++) arr[i] = i;
```

- We try to find code that has been *almost* written like this!
- If many do something similar, but one does it differently, it might be a bug

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- We try to find code that has been *almost* written like this!
- If many do something similar, but one does it differently, it might be a bug
- Usually relies on AST patterns with minimal binding information

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3. More Sophisticated Fronts

A Best Friend for Life: Control Flow Graph (CFG) [CT22]

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Directed graph representing all possible execution paths of a program. Usually uses *basic blocks* as nodes.

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1 int a = 42;                                java
2 while(a > 0) {
3     a = a + 1;
4     a = a / 2;
5 }
6 System.out.println(a);
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A Best Friend for Life: Control Flow Graph (CFG) [CT22]

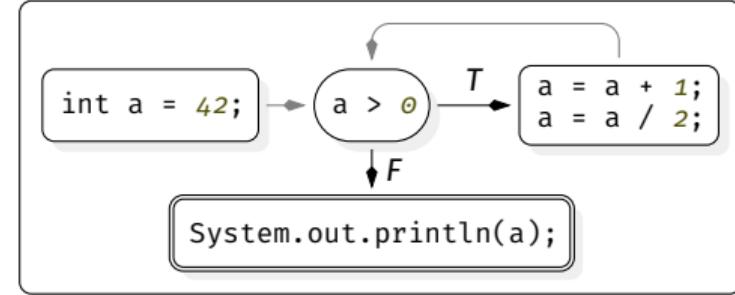
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CFG

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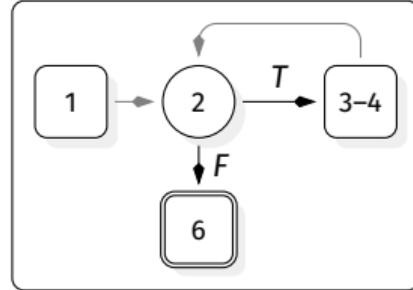
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CFG

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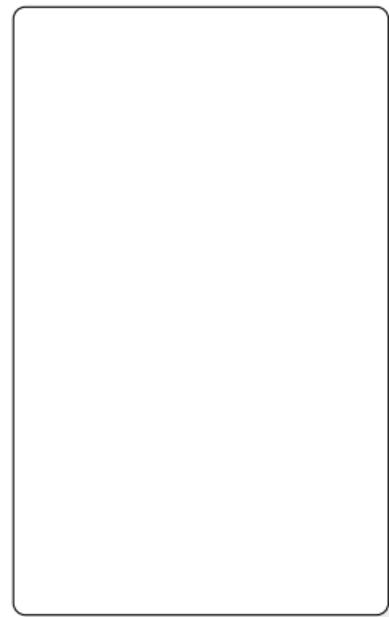
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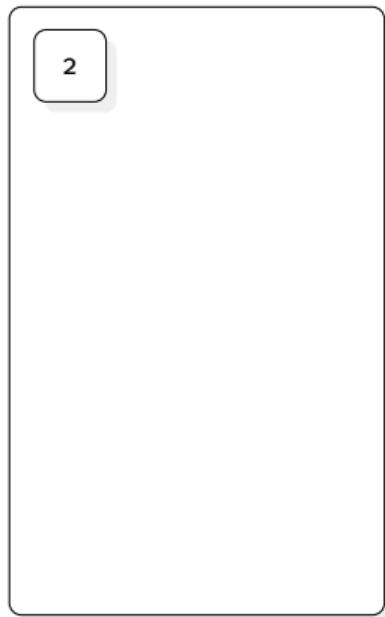
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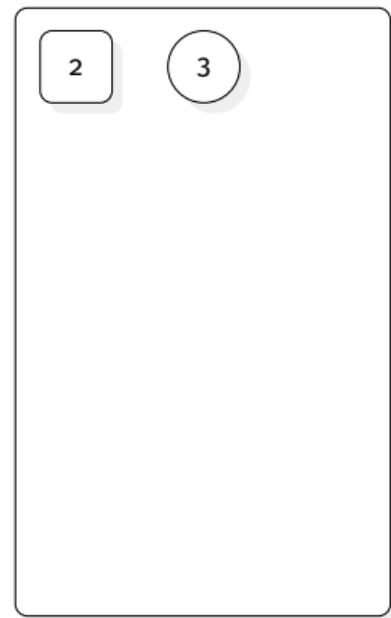
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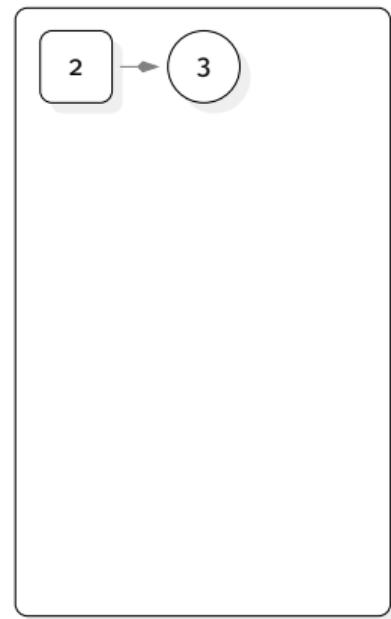
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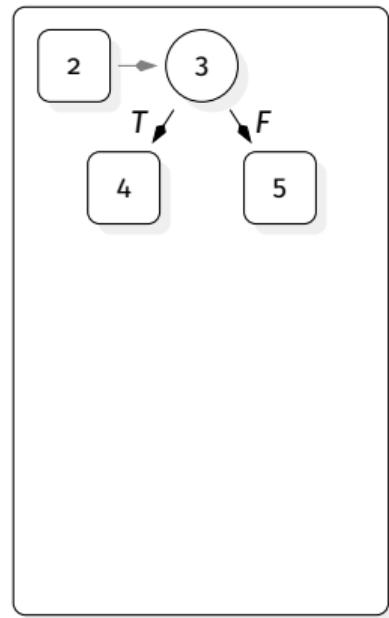
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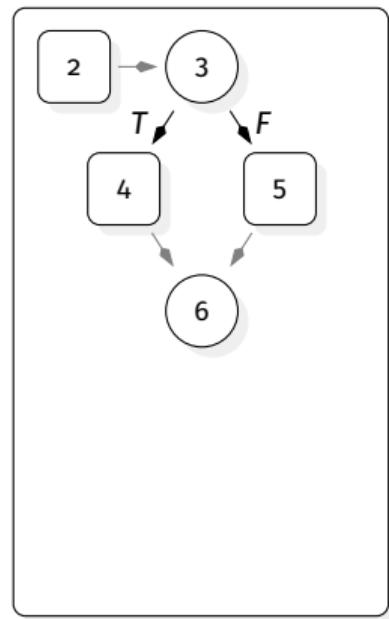
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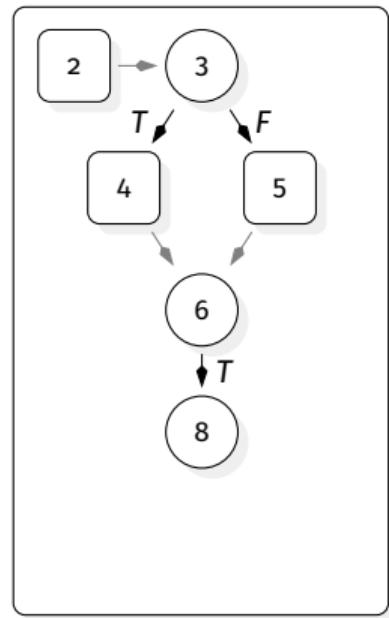
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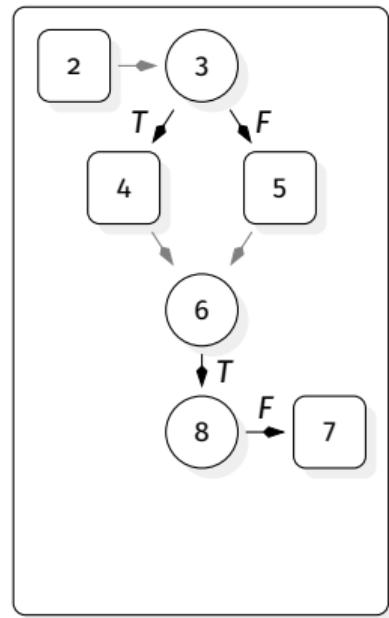
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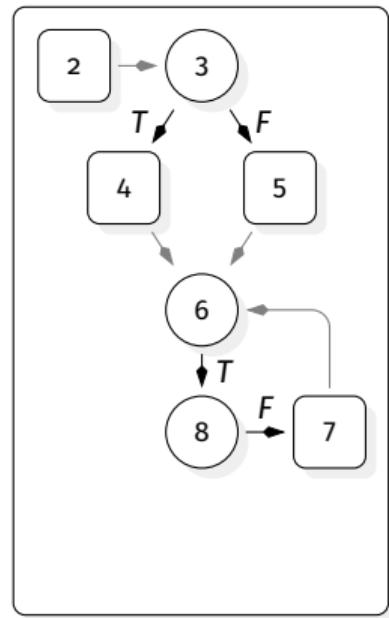
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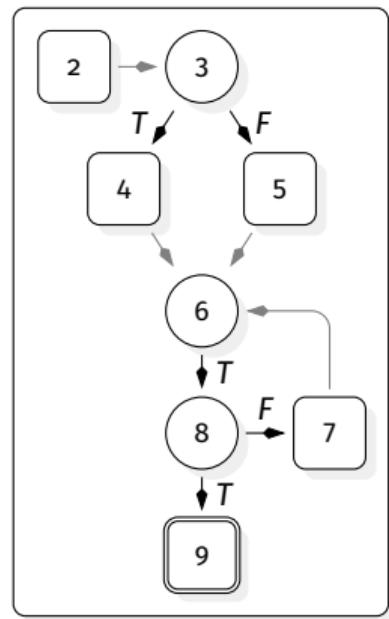
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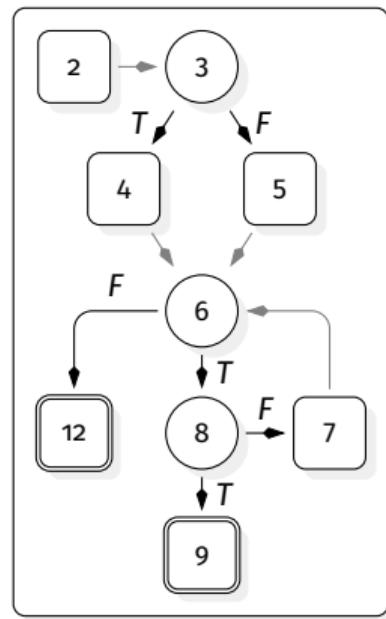
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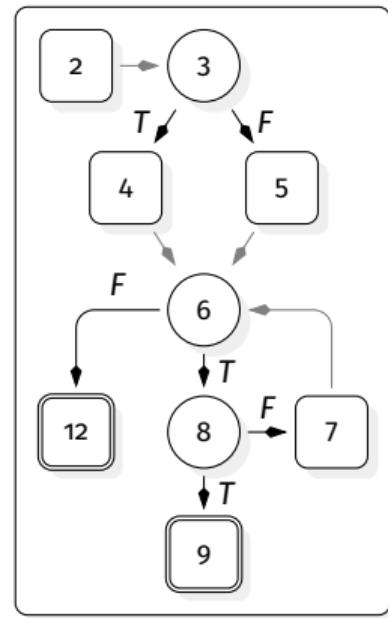
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java

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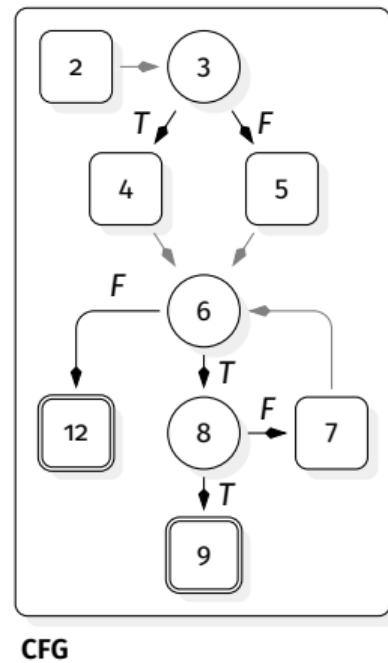


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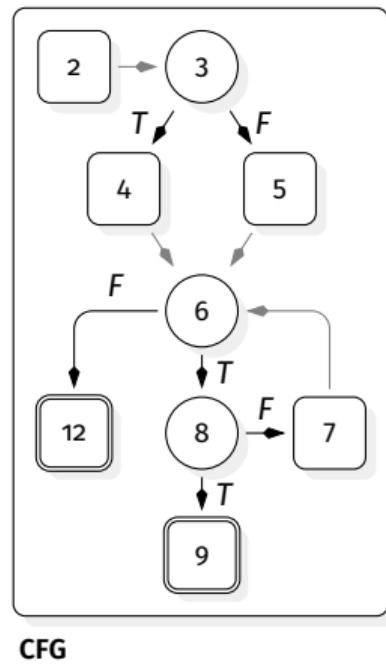
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E.g., nodes not reachable from the start node.



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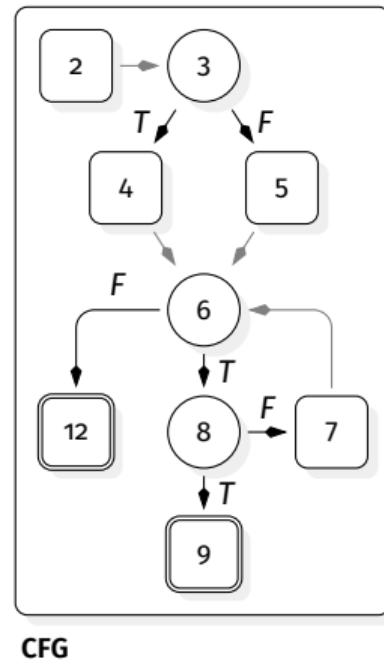
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- How to find dead code?
E.g., nodes not reachable from the start node.
- How to find infinite loops?
E.g., nodes that cannot reach an exit node.



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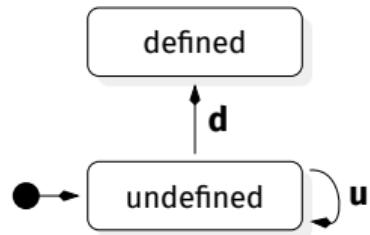
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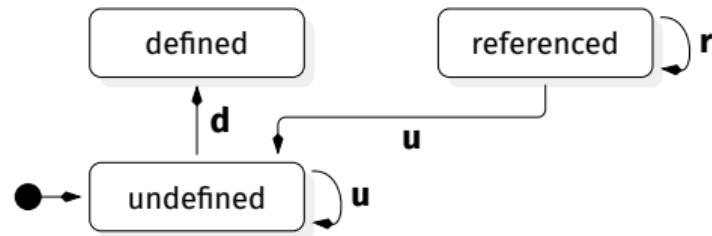


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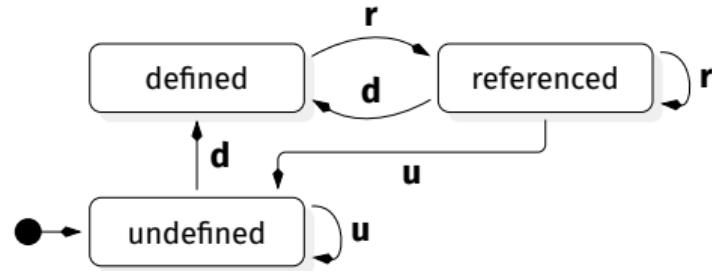


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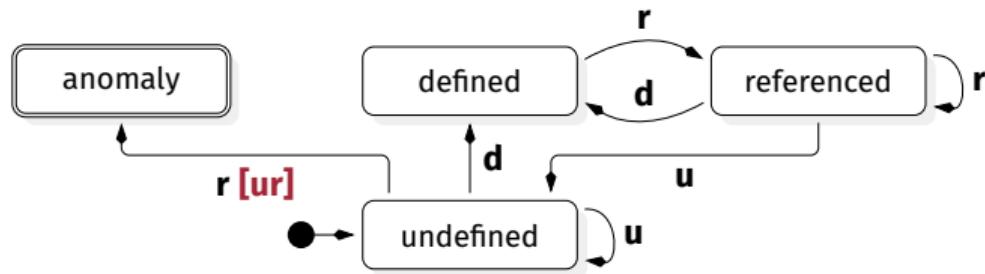


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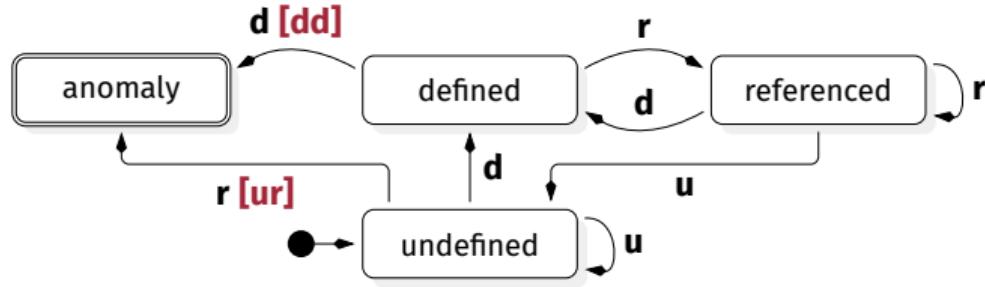


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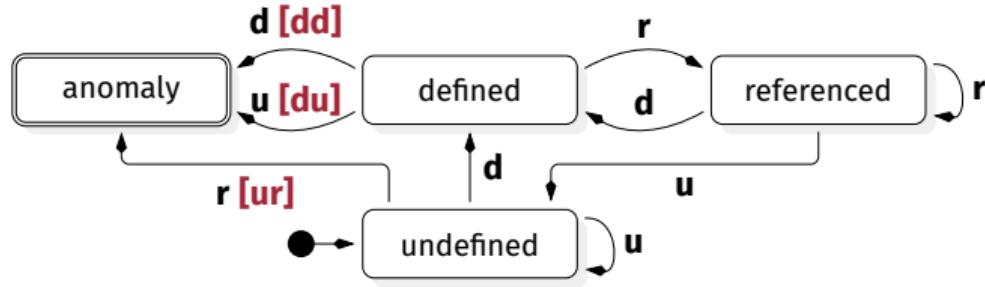


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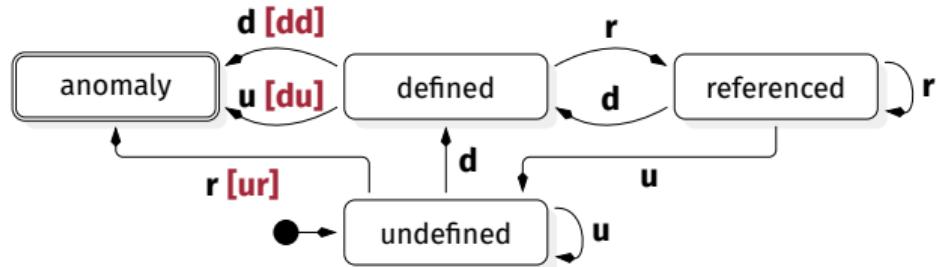
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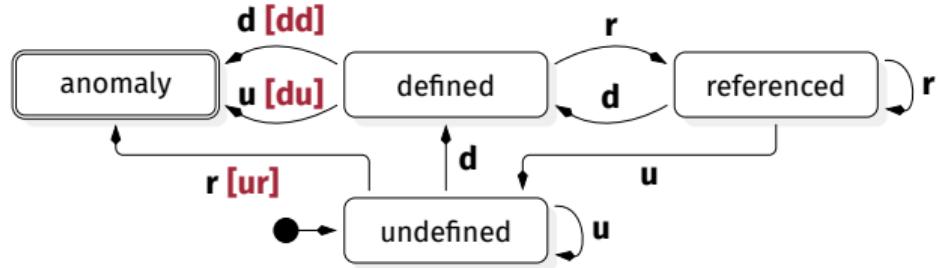
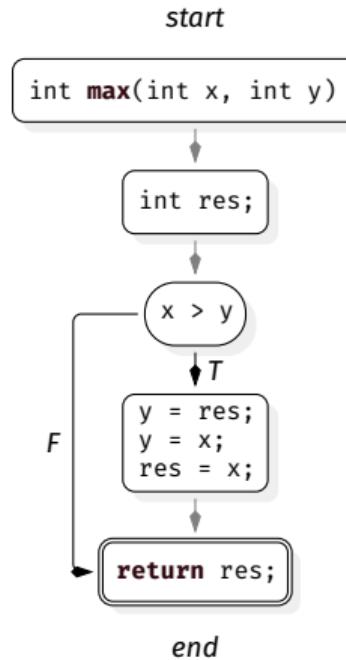
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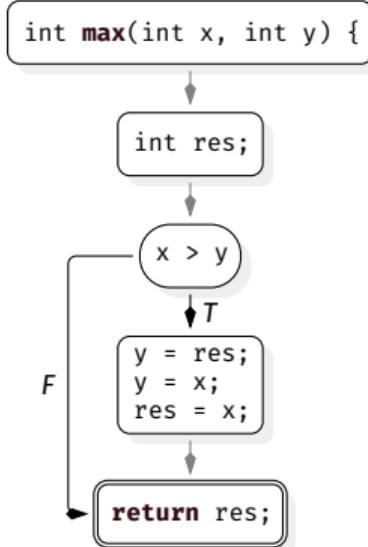
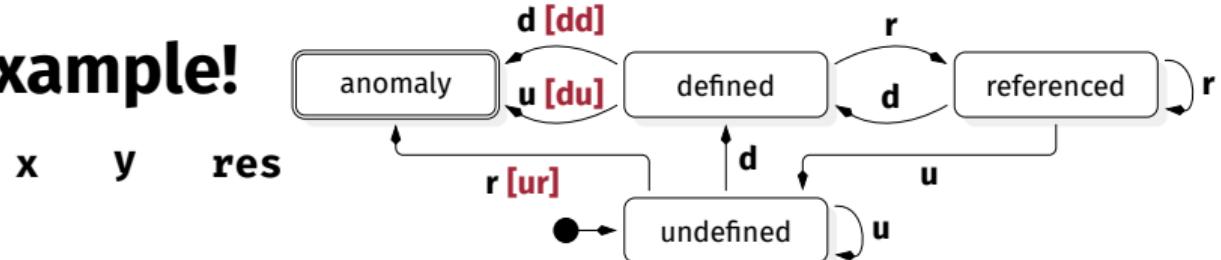
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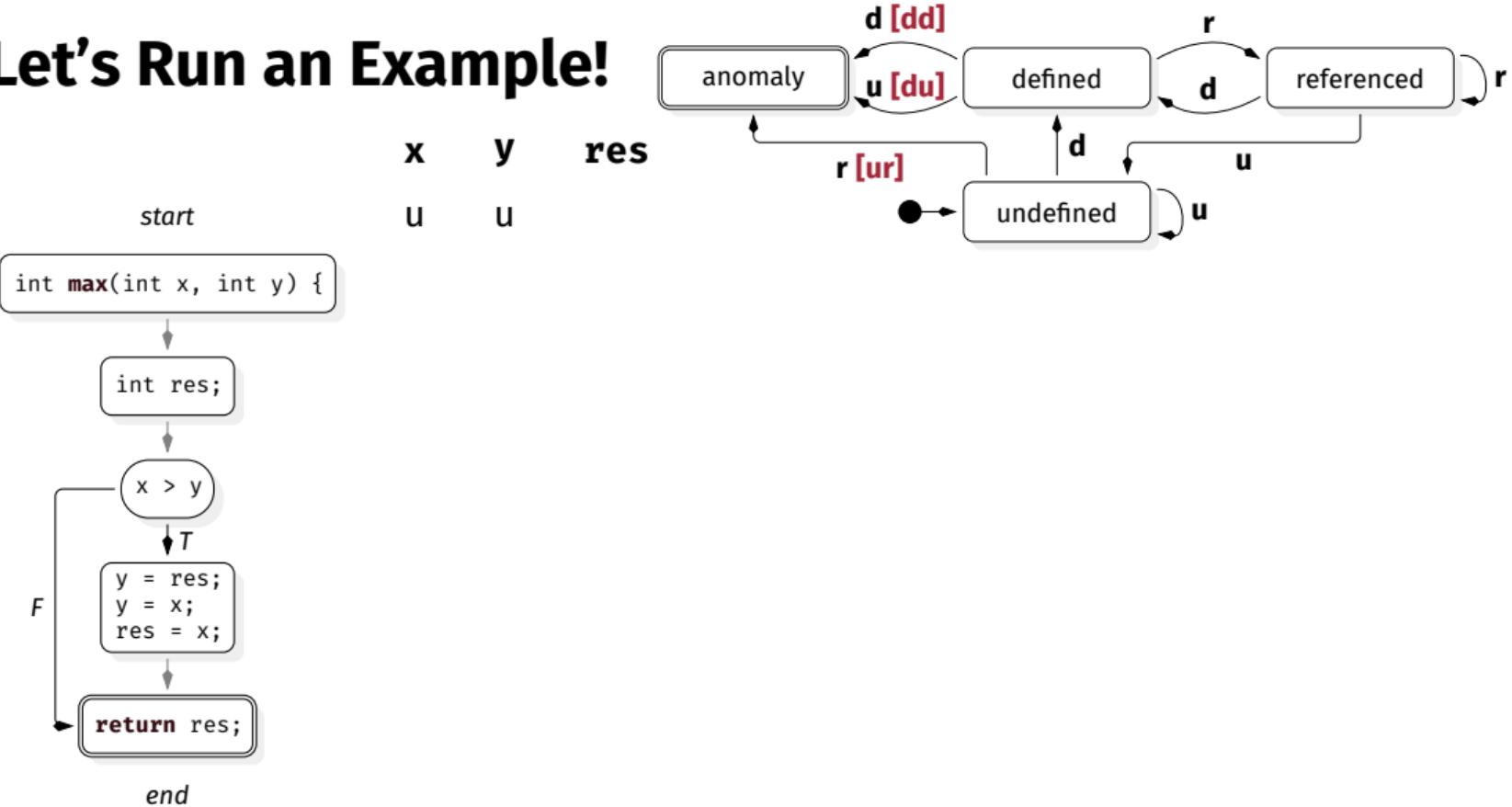
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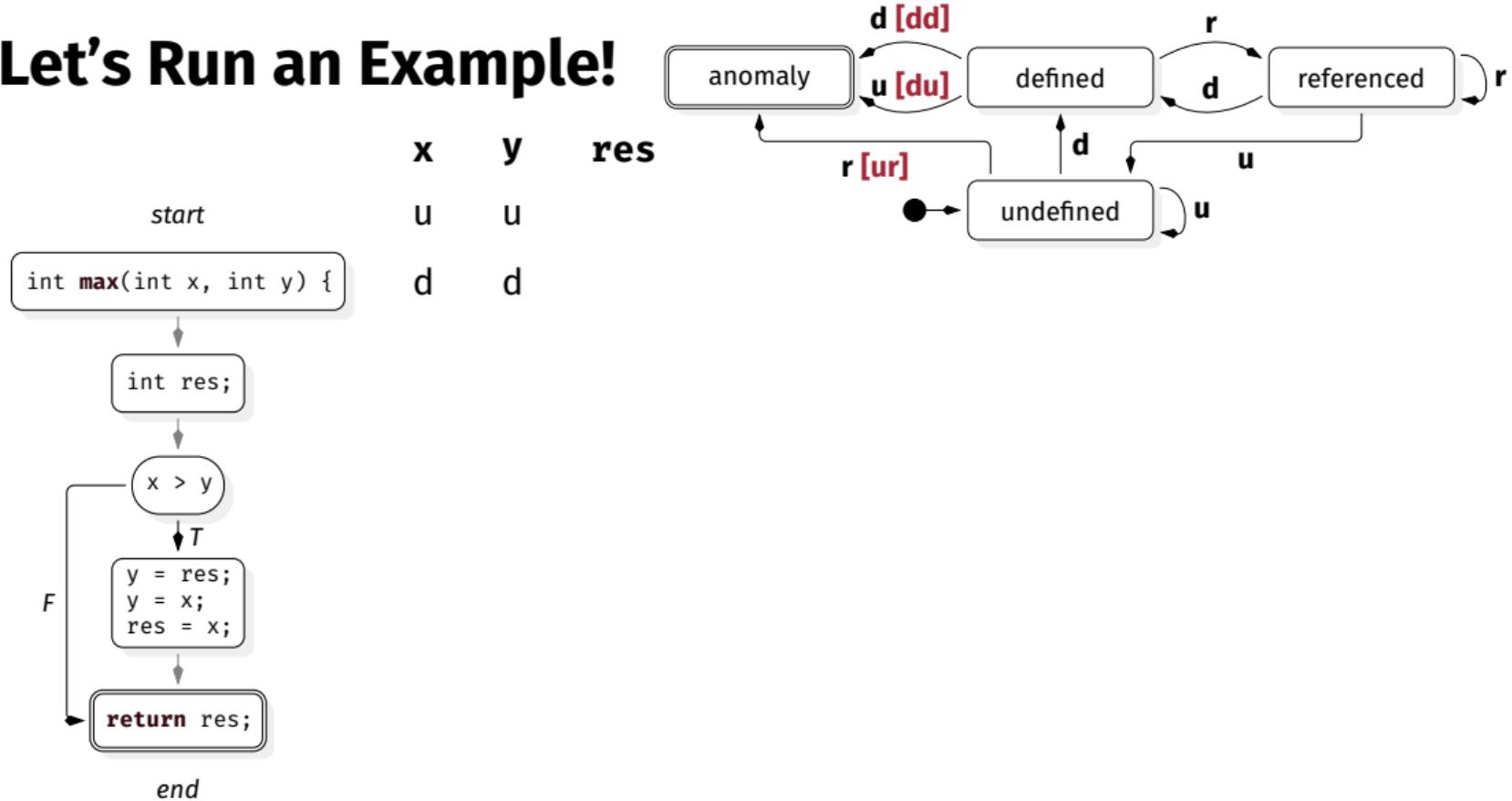
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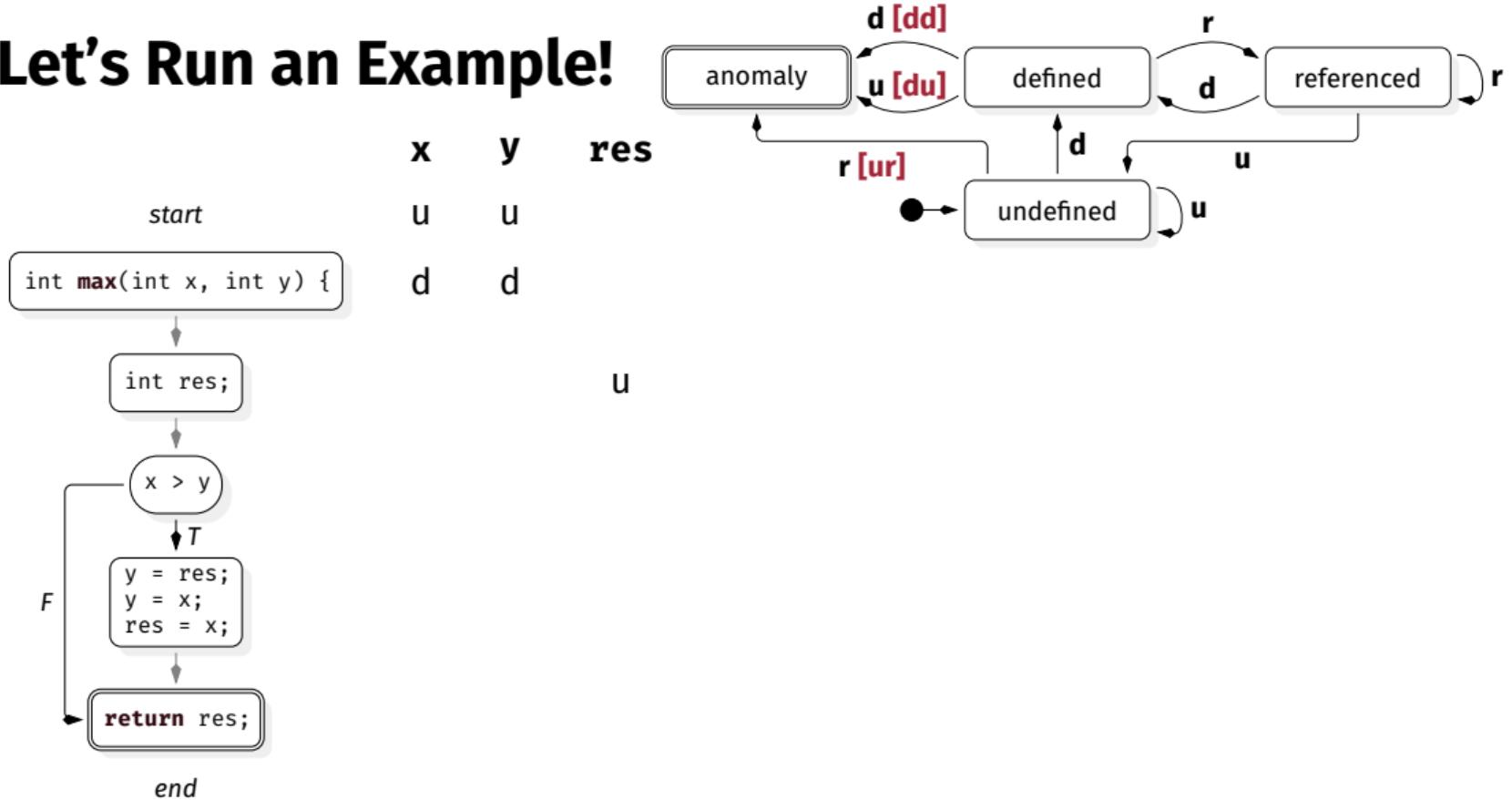
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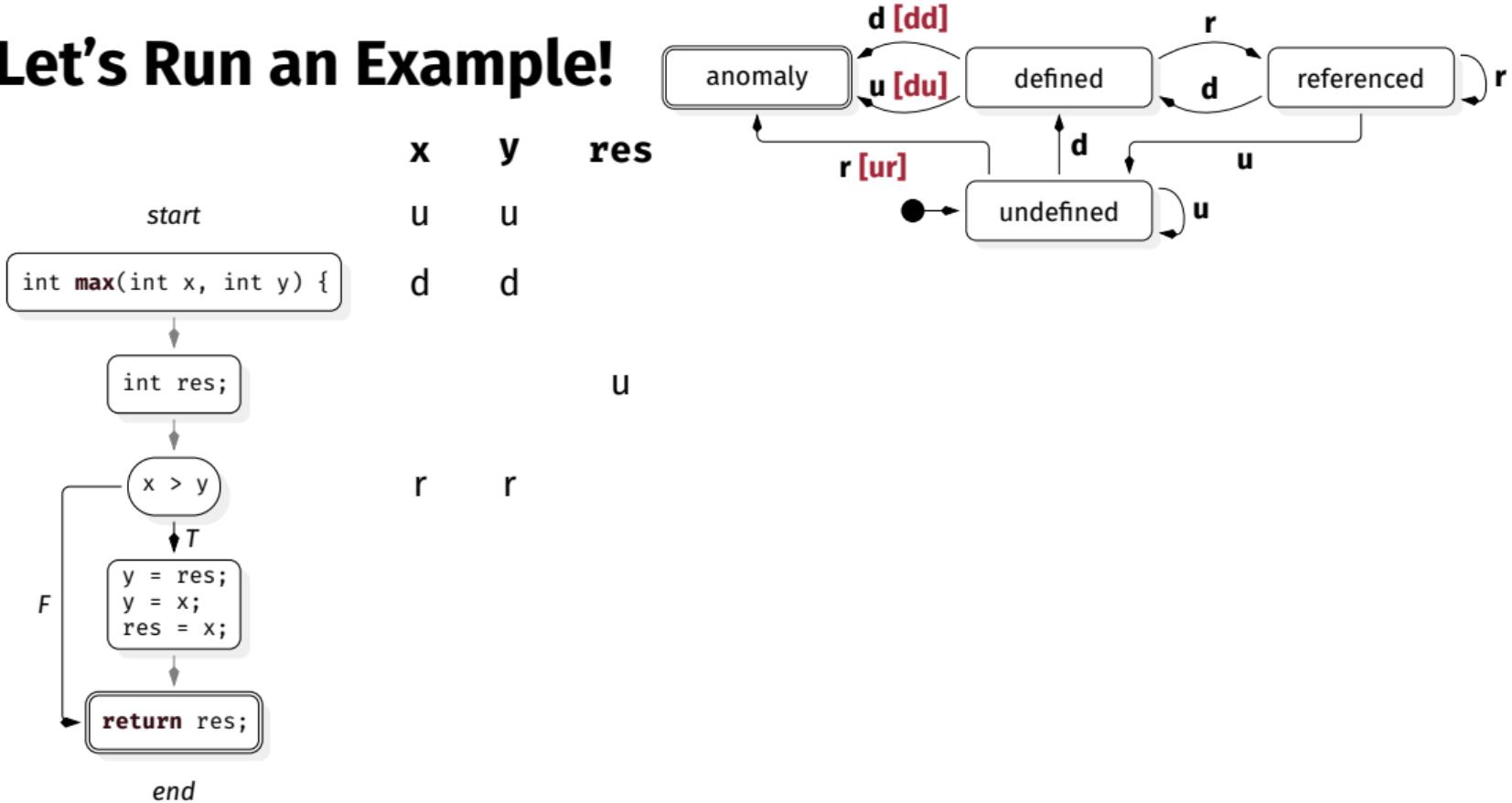
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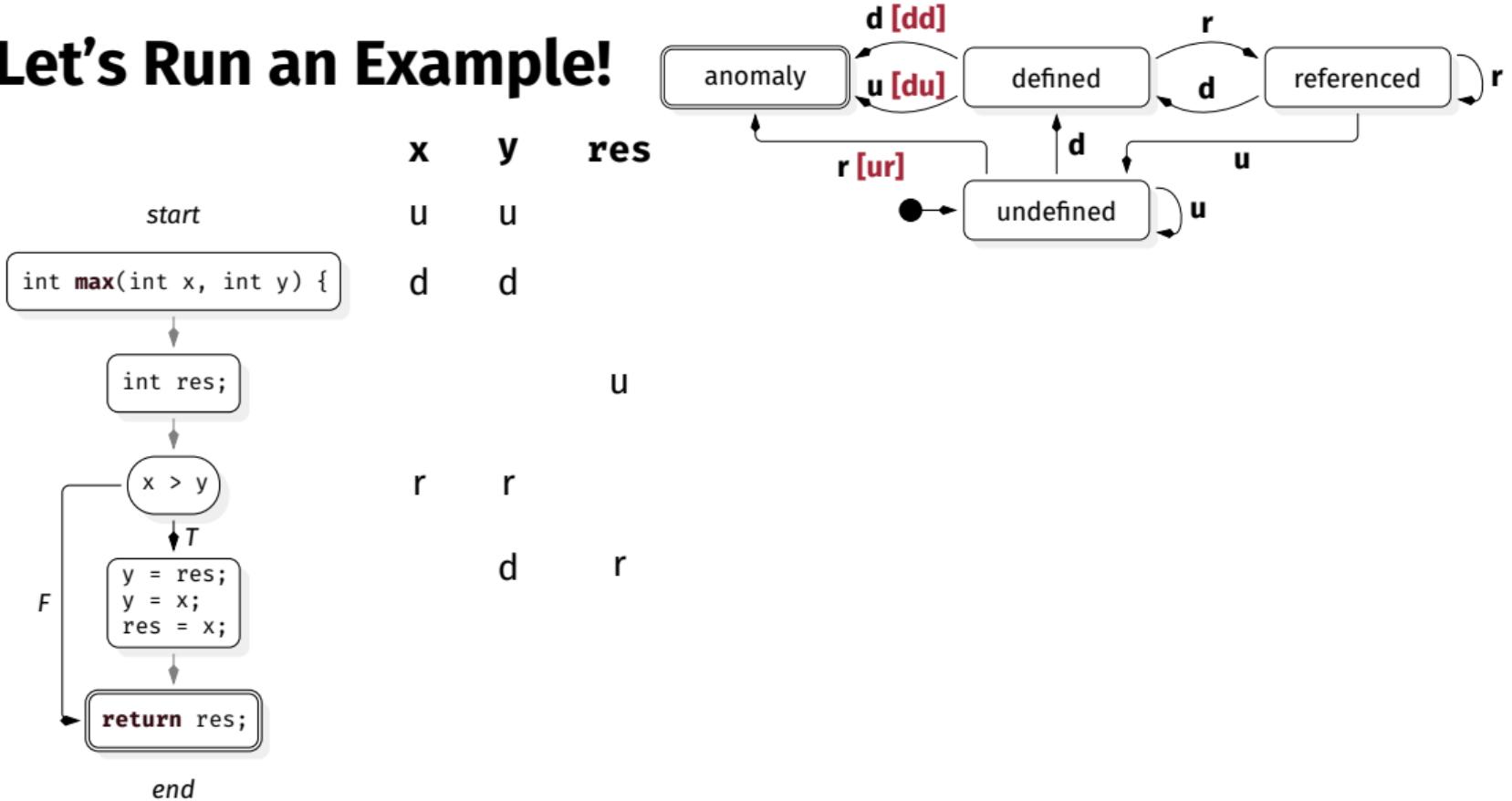
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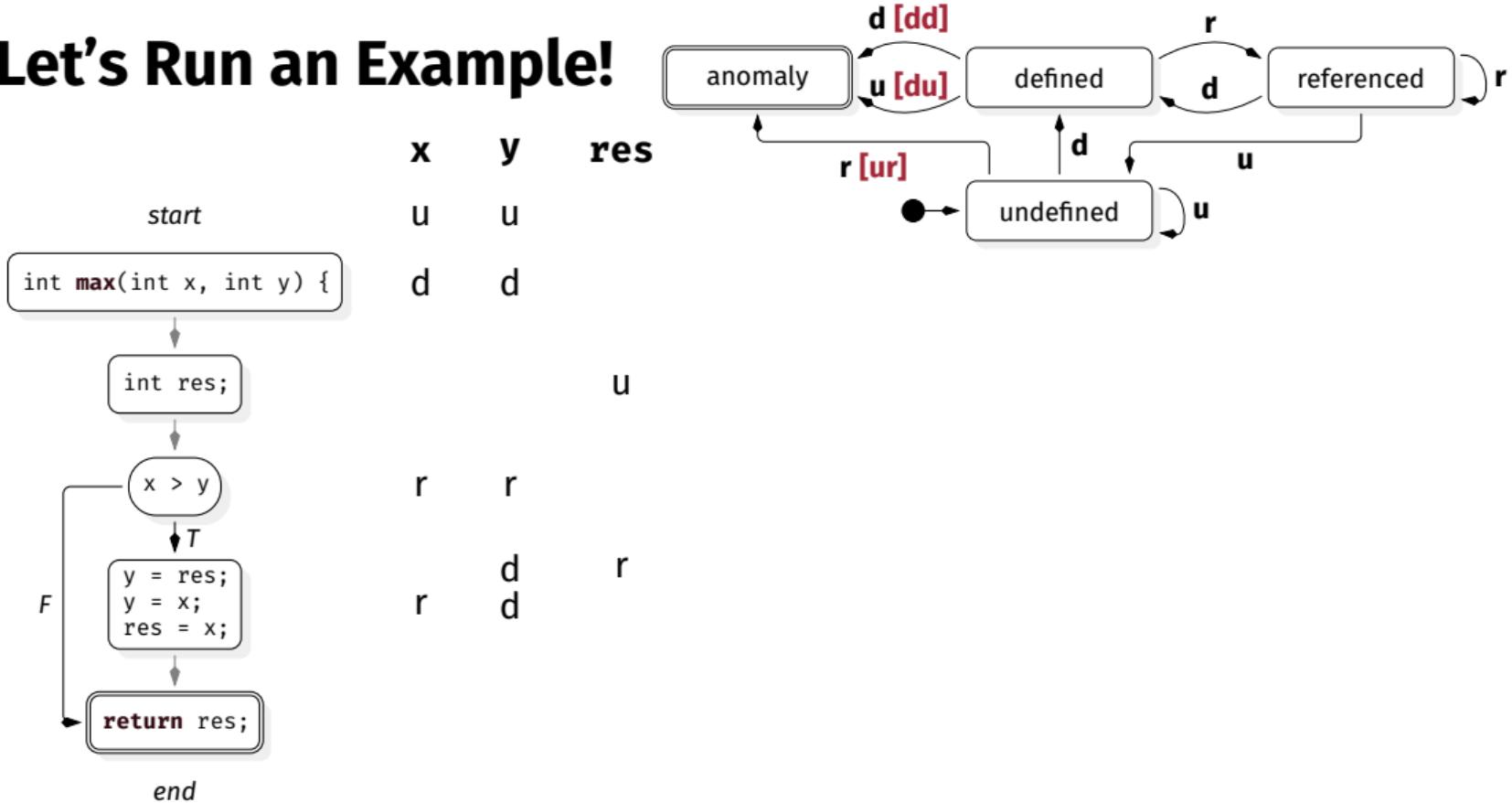
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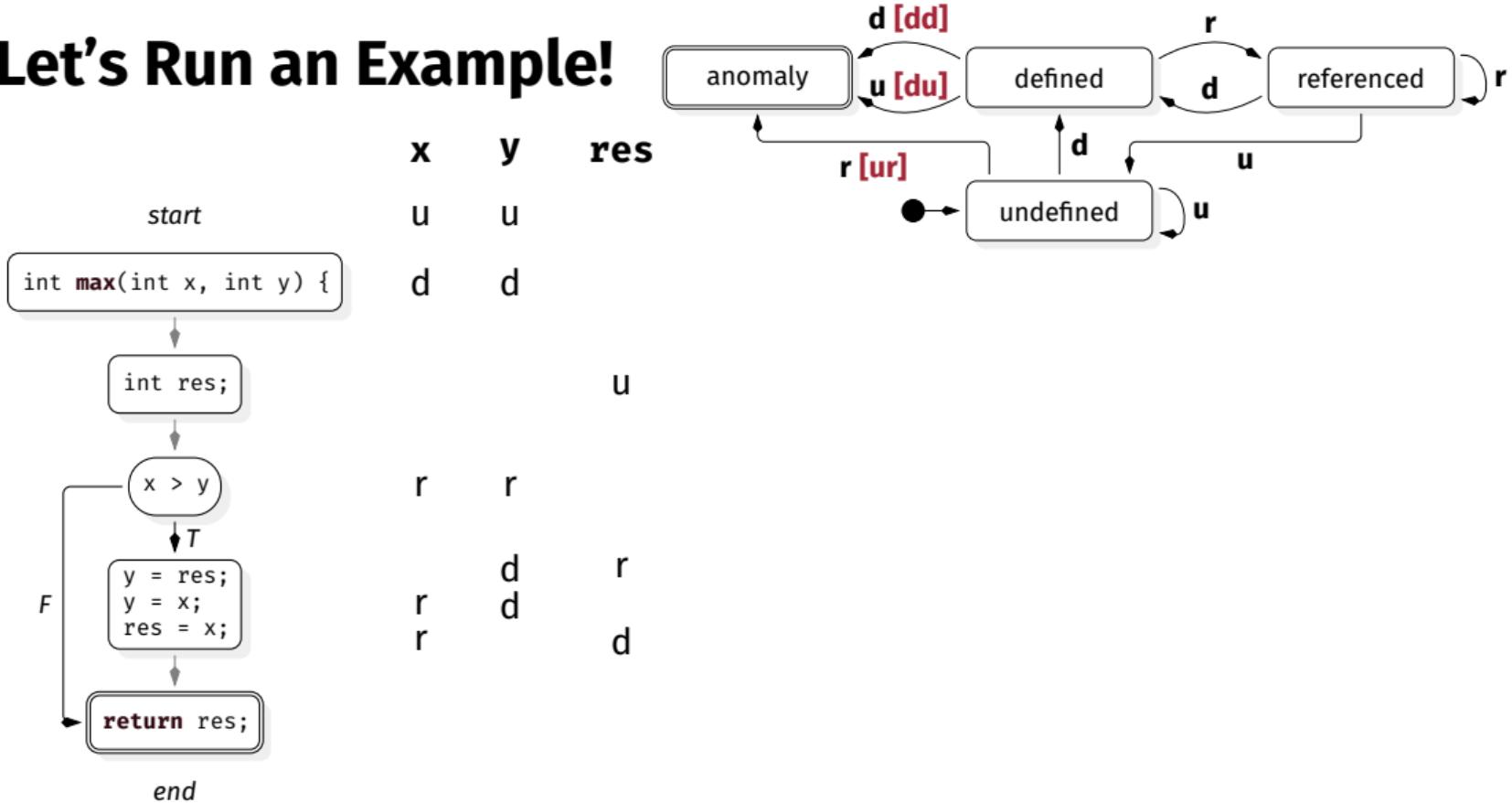
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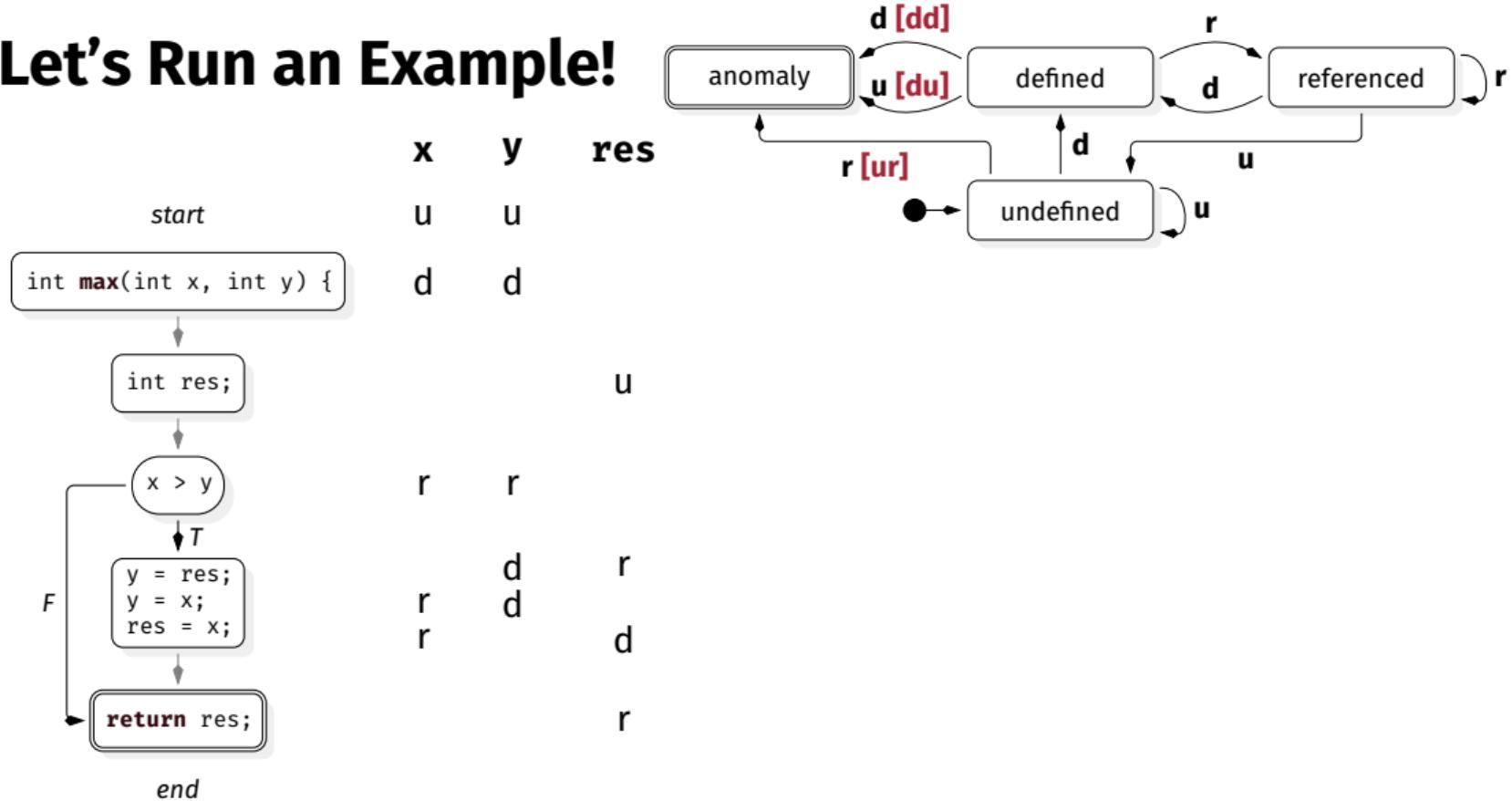
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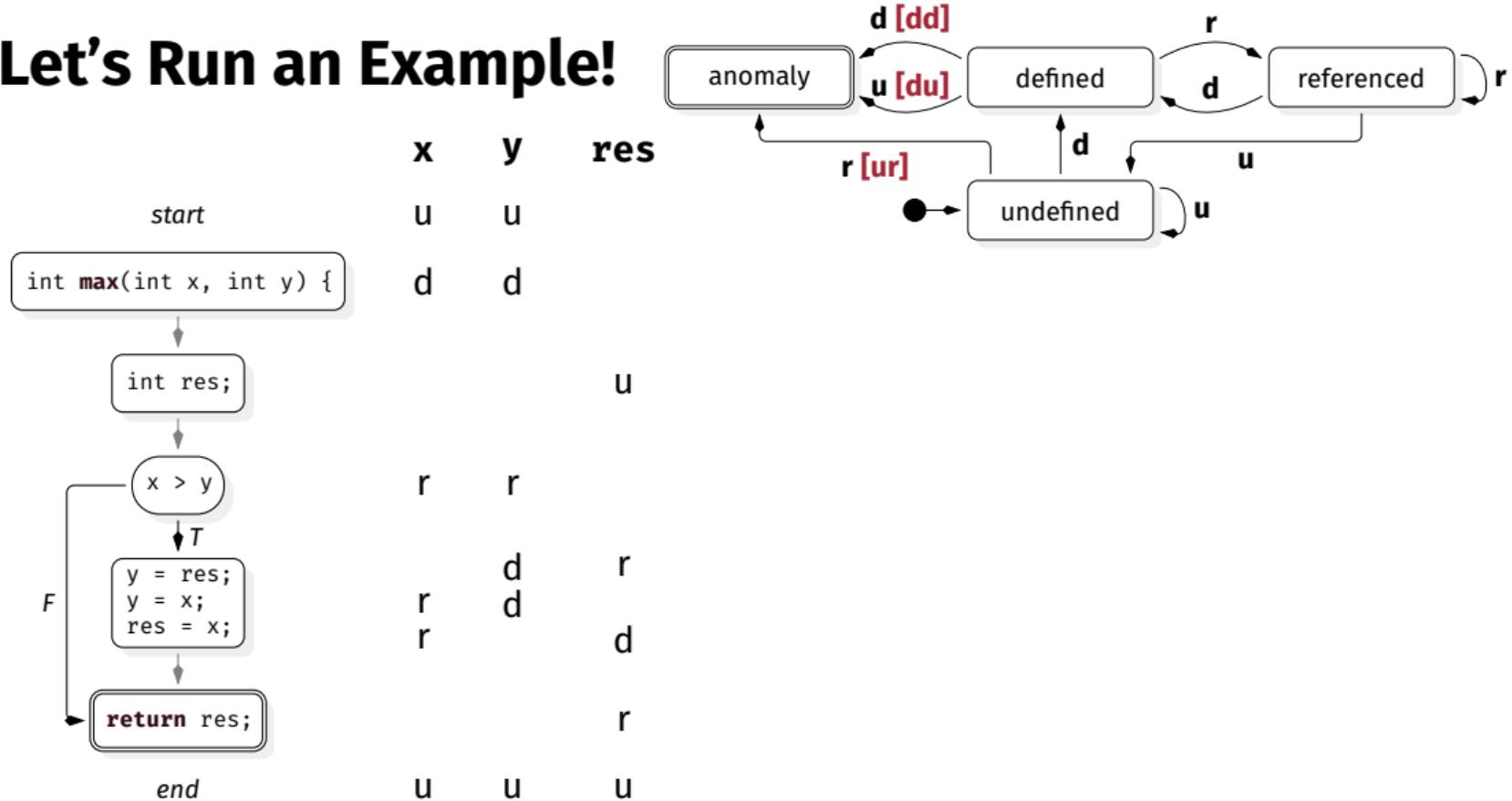
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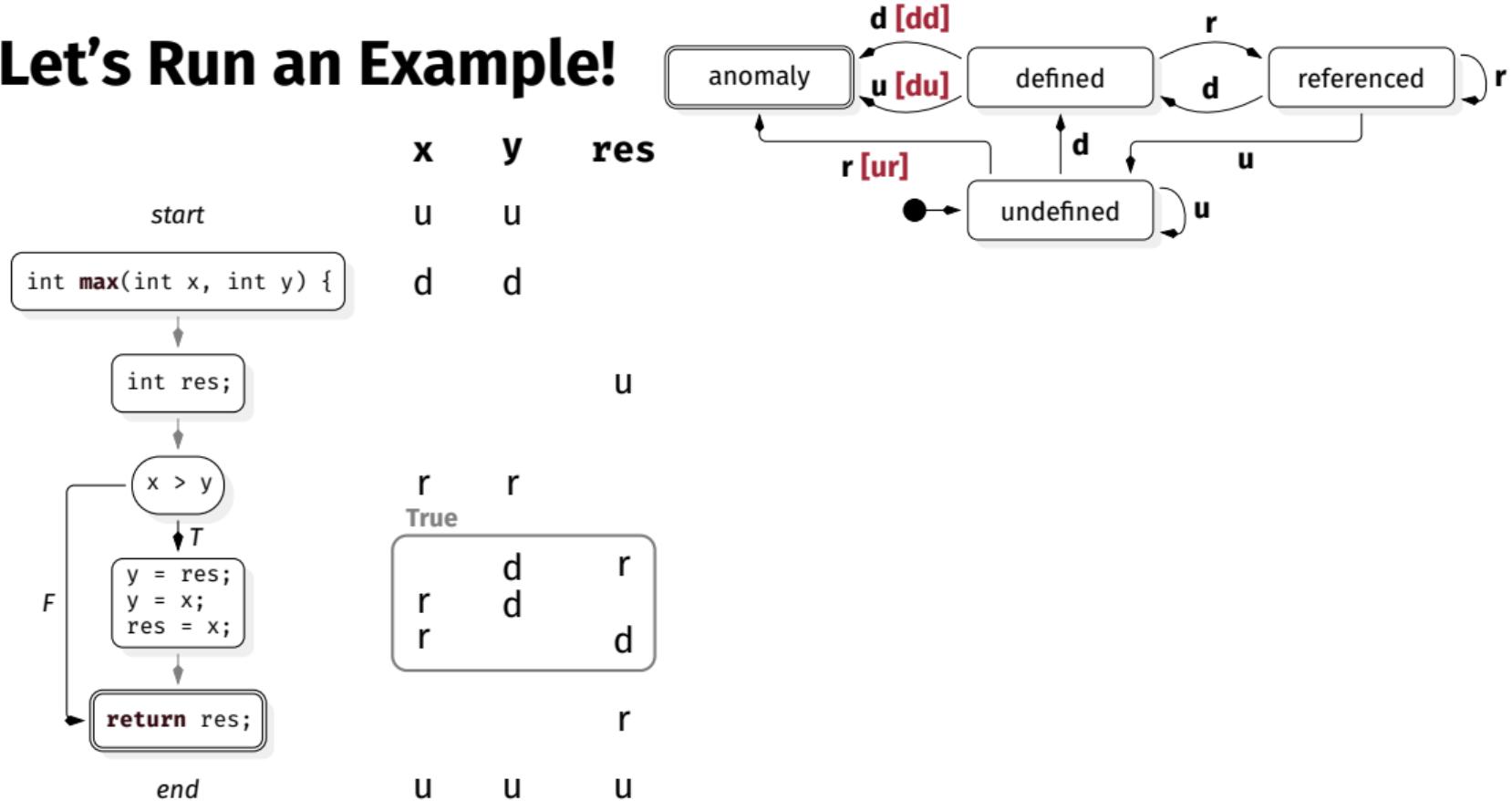
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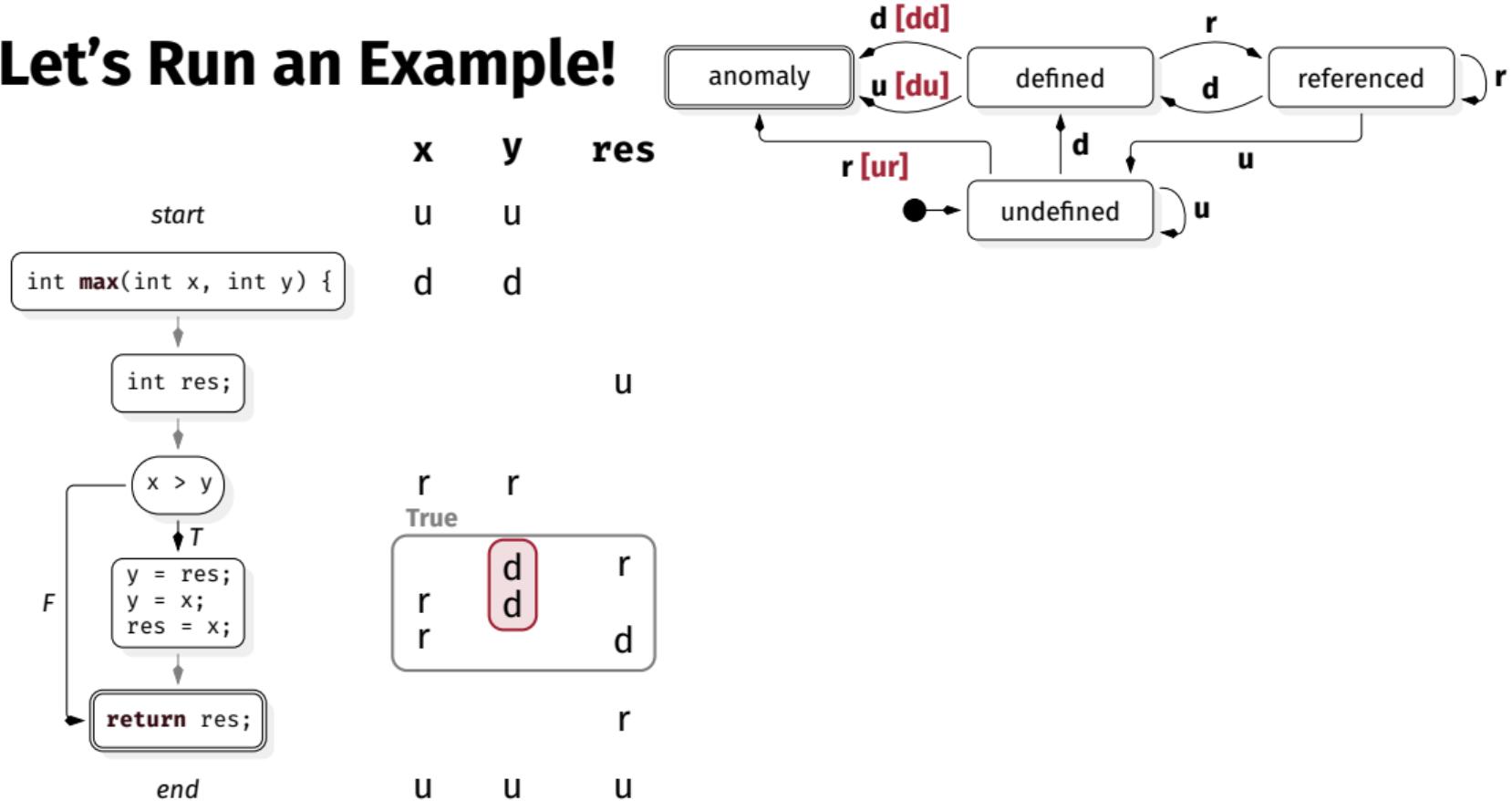
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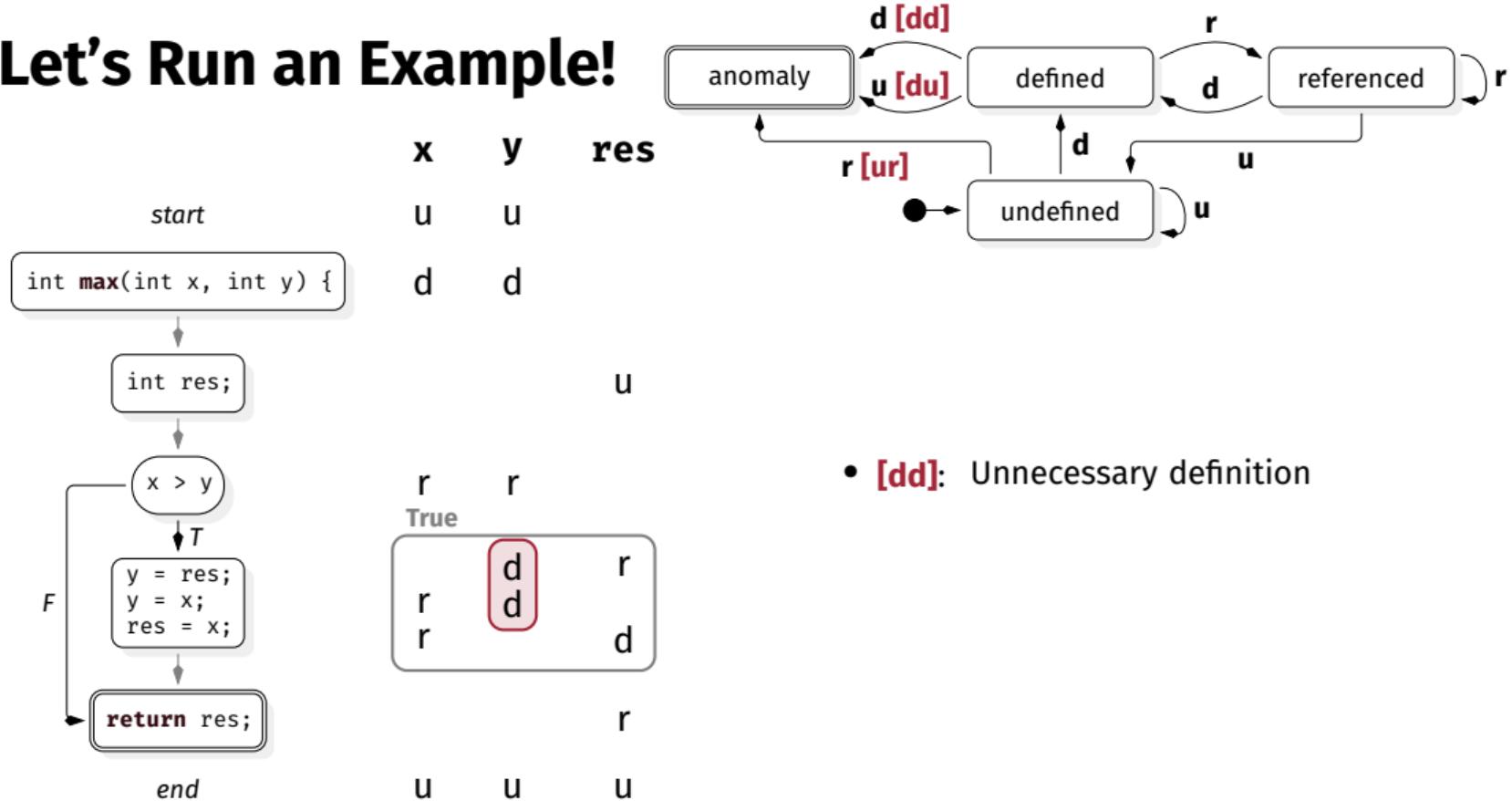
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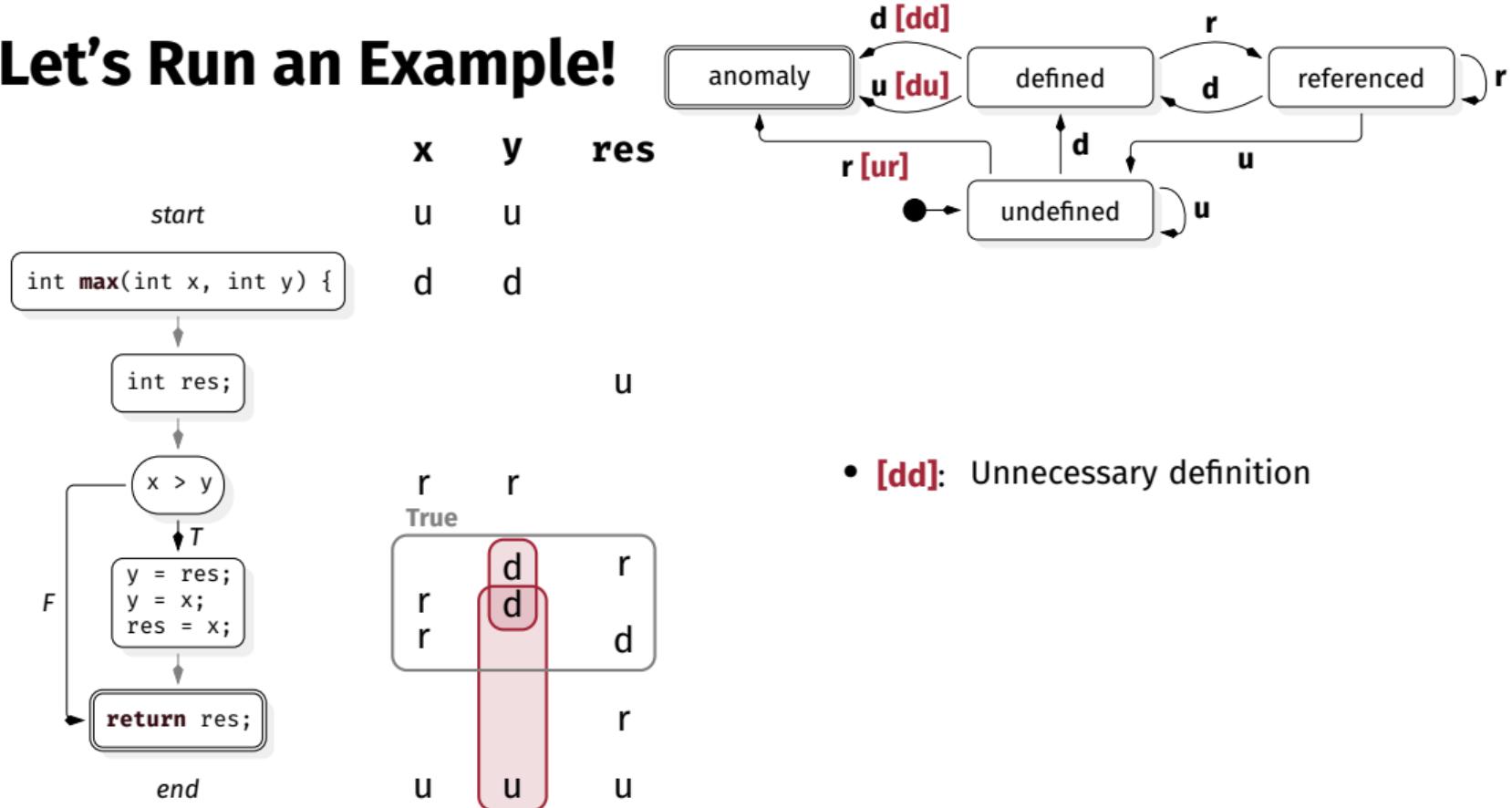
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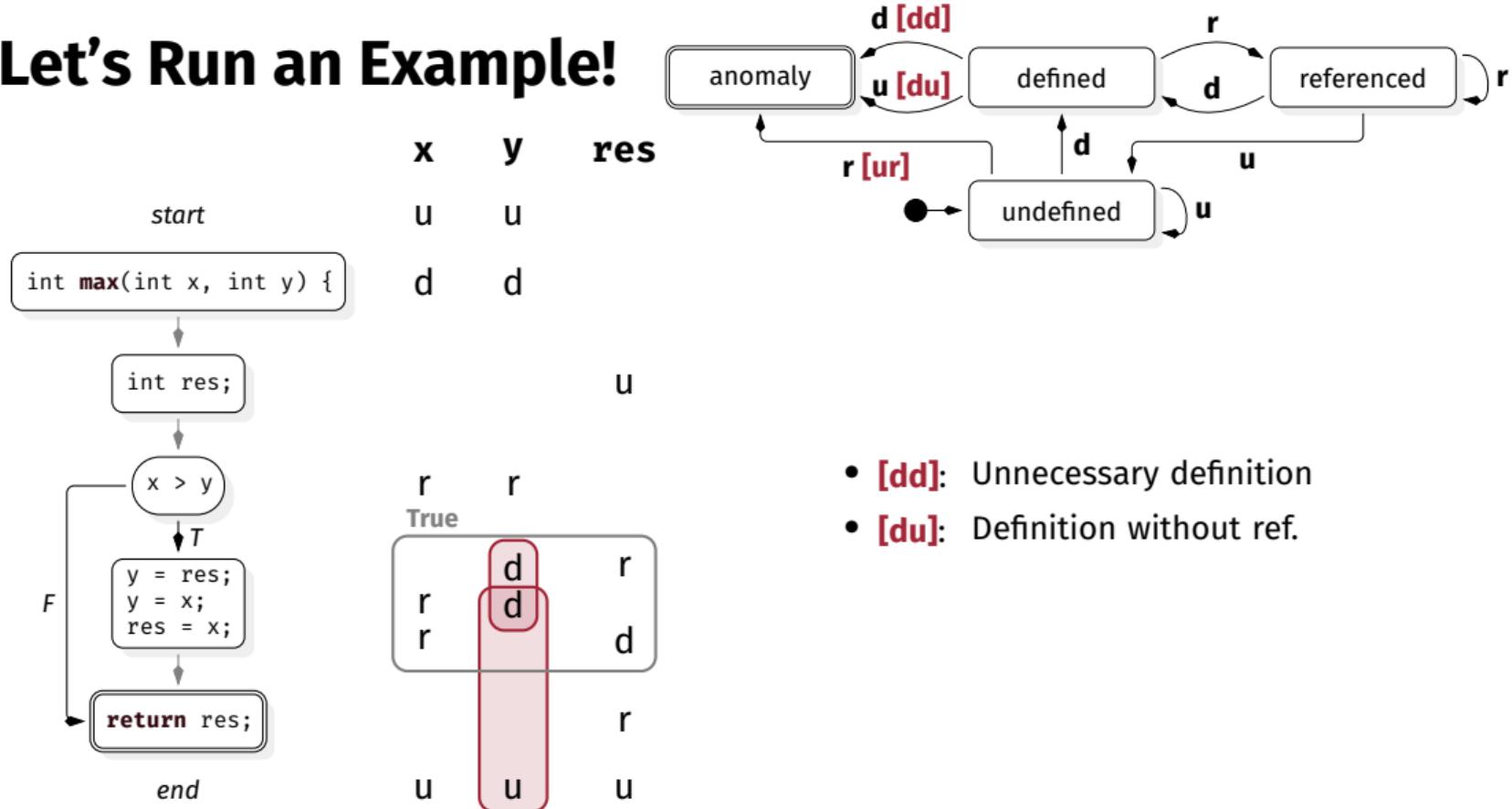
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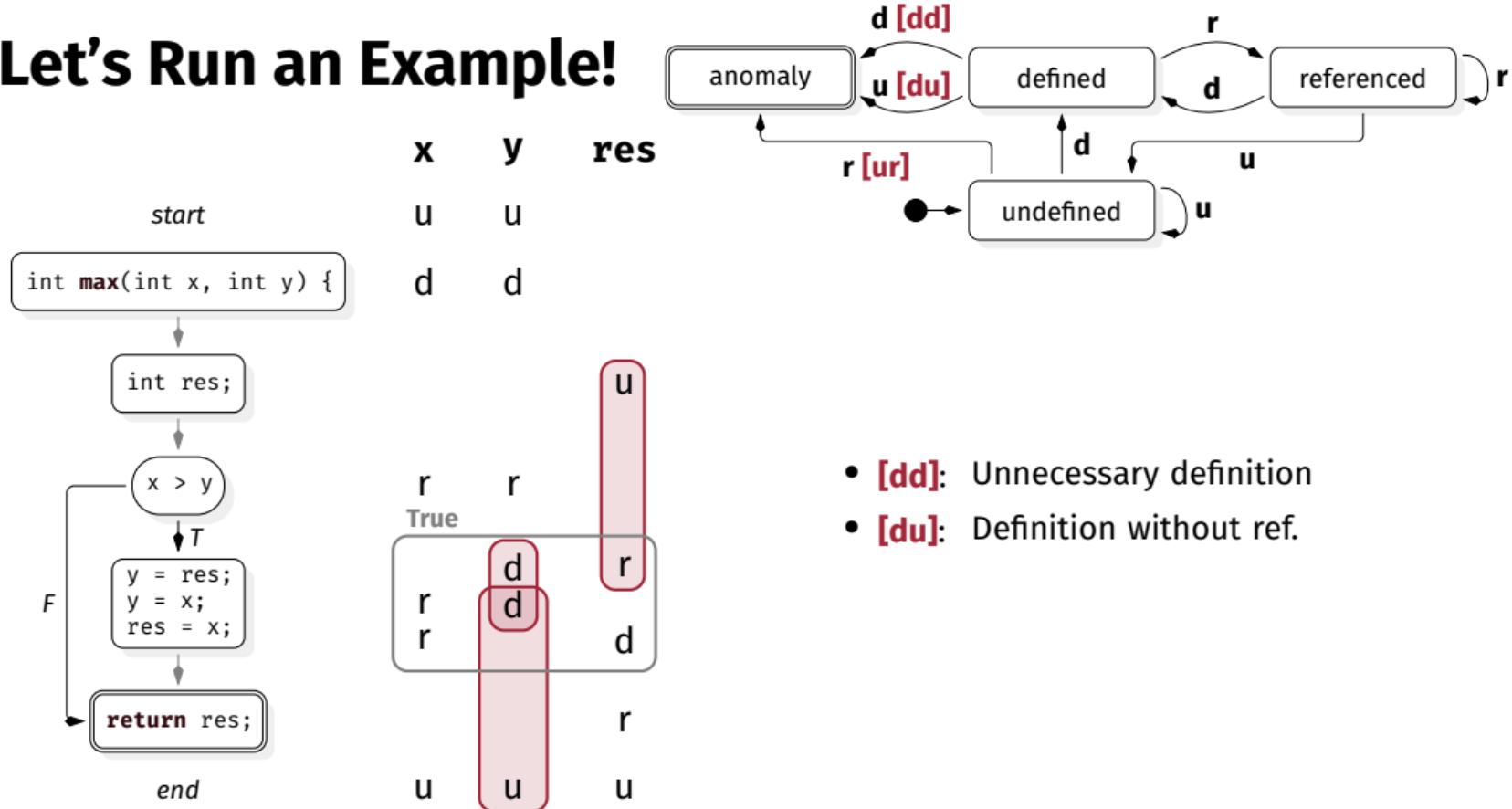
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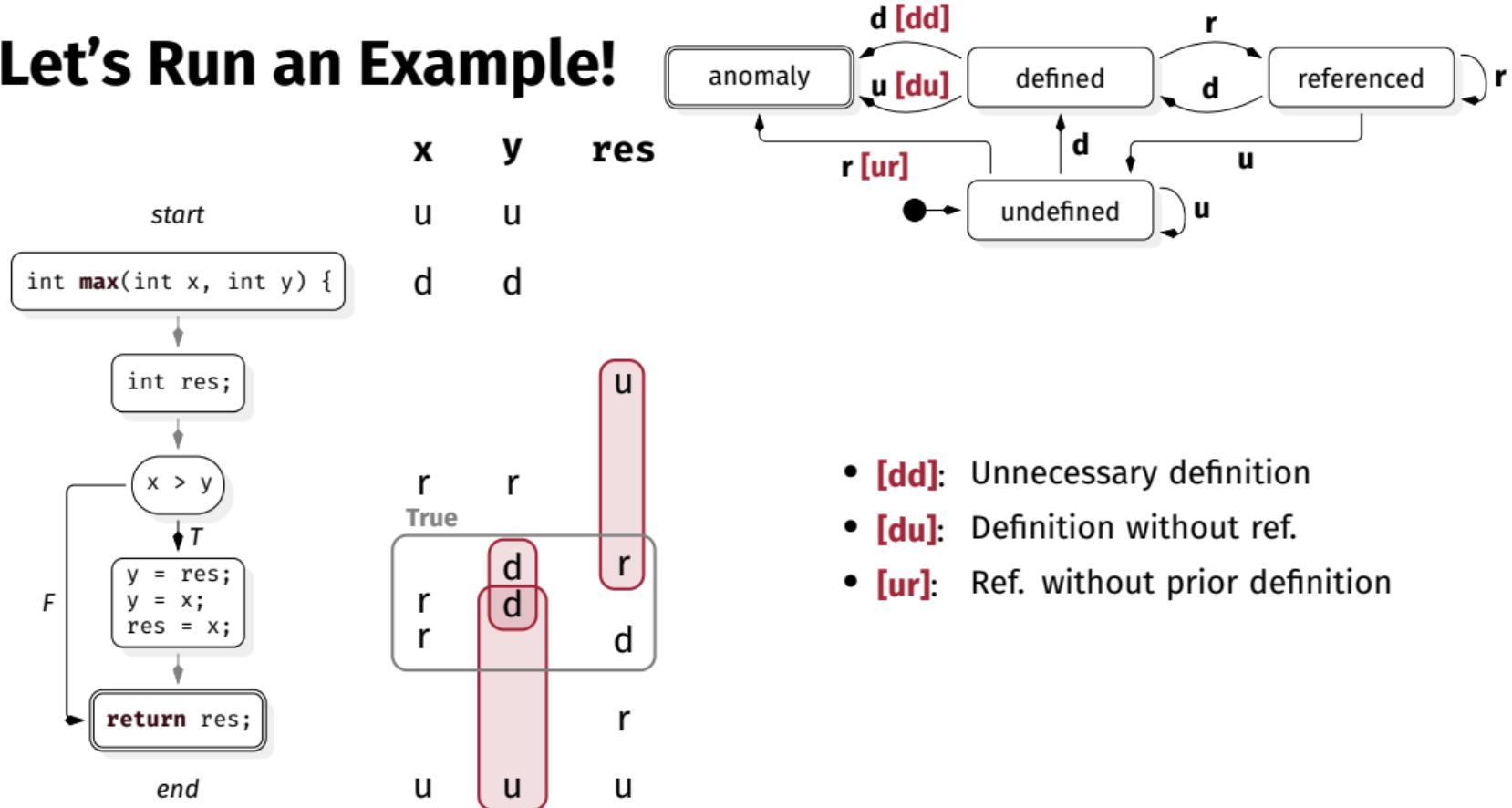
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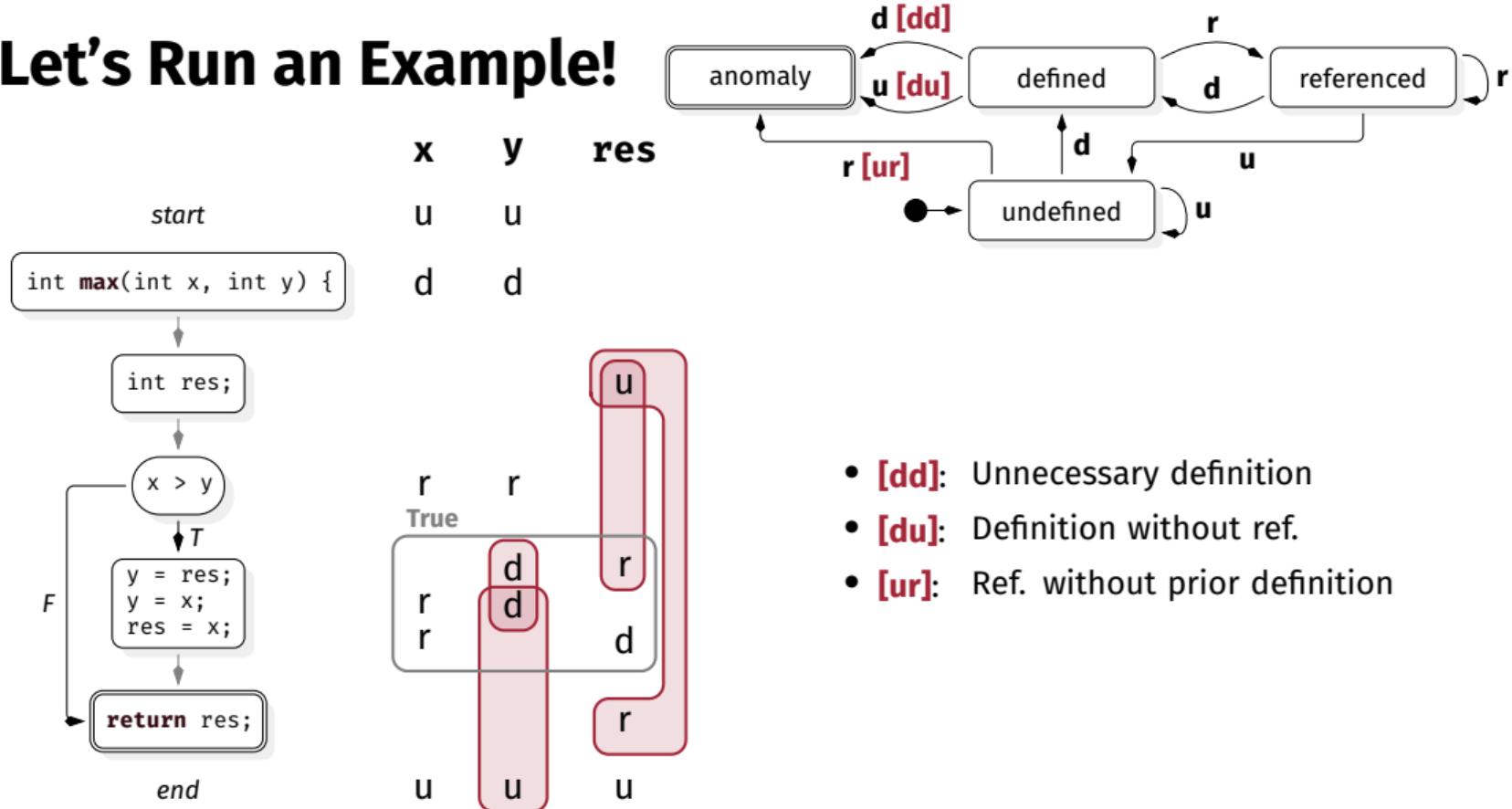
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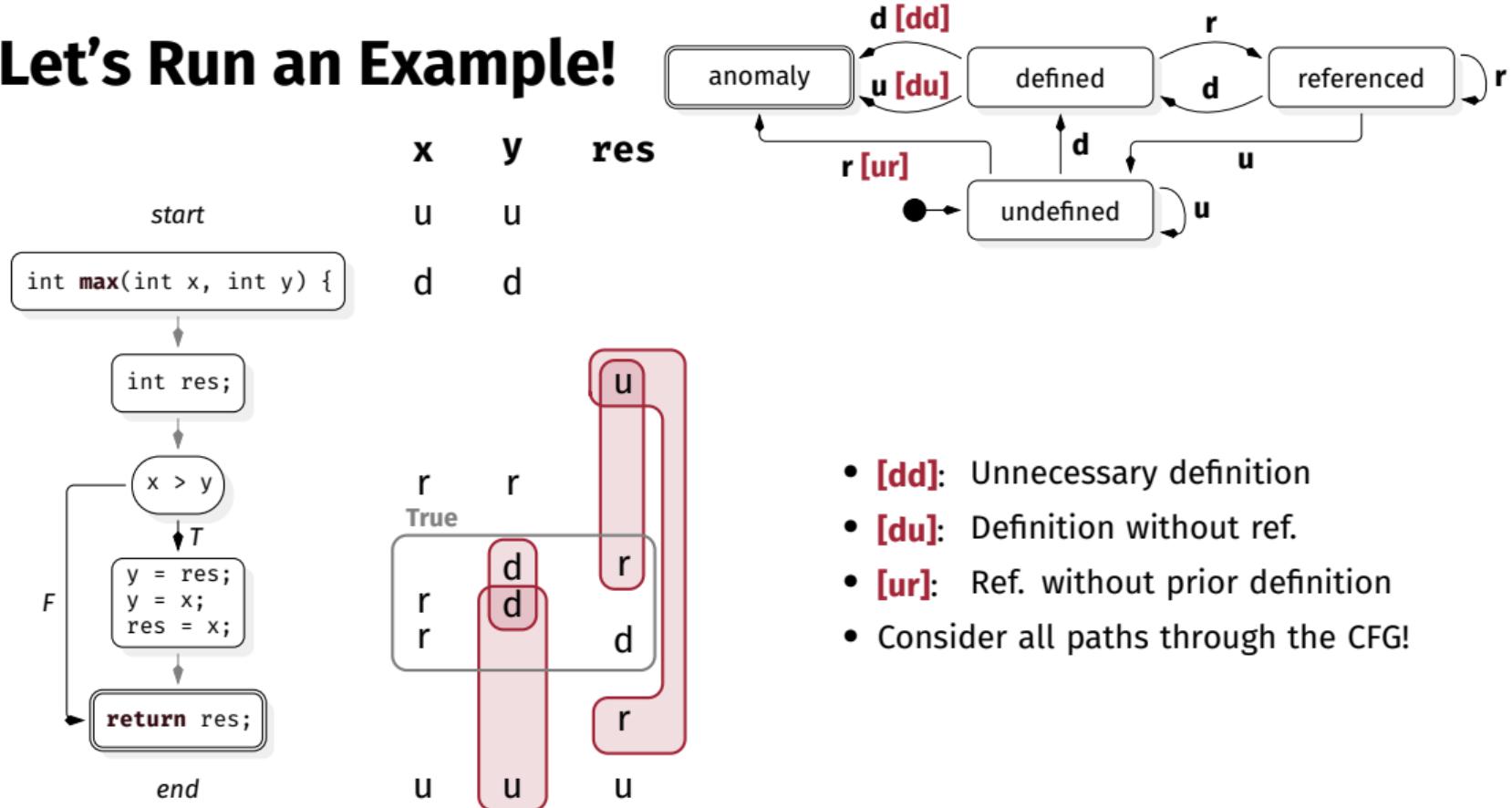
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- A plethora of techniques try to address these challenges from various perspectives
- One prominent technique is *abstract interpretation*^[Cou21]
We'll tackle this in the second lecture!

4. Important Terminology

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E.g., possible division by zero

Liveness and Safety Properties

[RY20; Lam77]

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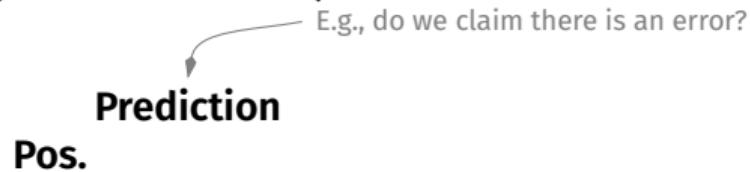
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E.g., do we claim there is an error?

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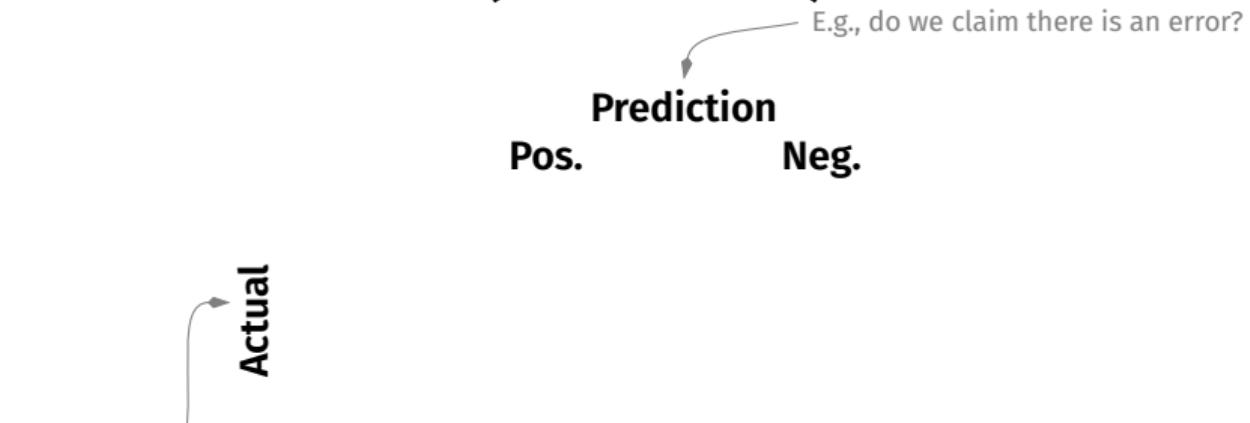


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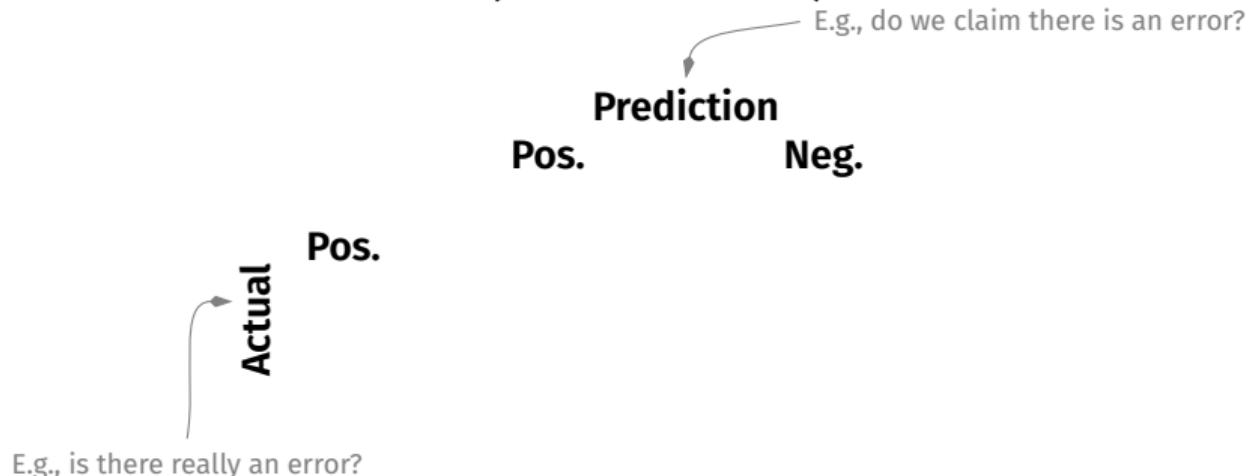
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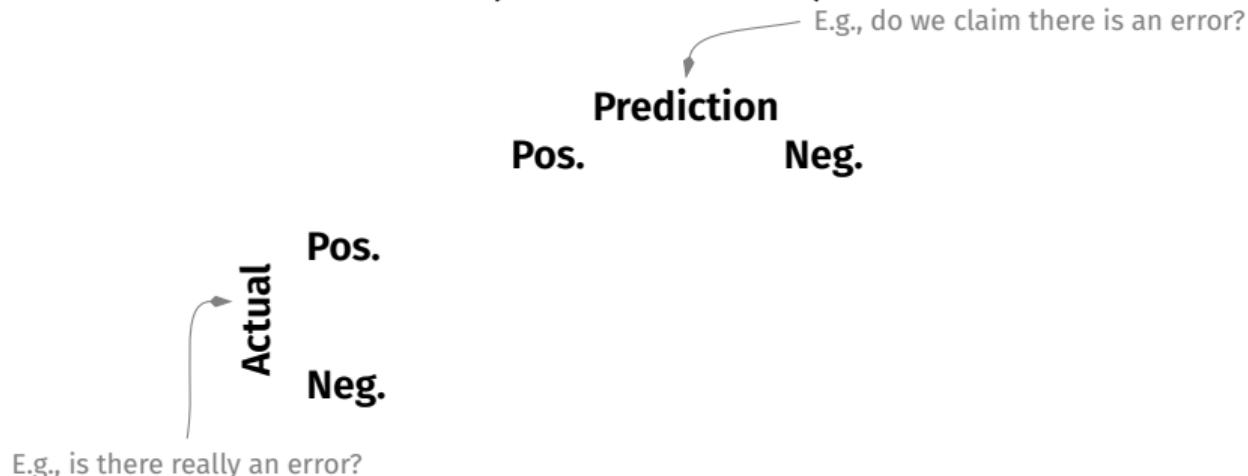
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A confusion matrix diagram with 'Actual' on the vertical axis and 'Prediction' on the horizontal axis. The 'Actual' axis has two categories: 'Pos.' and 'Neg.'. The 'Prediction' axis also has two categories: 'Pos.' and 'Neg.'. The cell at the intersection of 'Actual Pos.' and 'Prediction Pos.' is labeled '(TP) True Positive' in green. The cell at the intersection of 'Actual Neg.' and 'Prediction Neg.' is labeled '(FN) False Negative' in green. A curved arrow points from the text 'E.g., do we claim there is an error?' to the '(TP)' cell. Another curved arrow points from the text 'E.g., is there really an error?' to the '(FN)' cell.

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- **Recall:** $TP / (TP + FN)$ (“how many errors did we find”)

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You better want completeness.

5. Outlook

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We will address these questions in the next lecture(s)!

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