Deducing Errors

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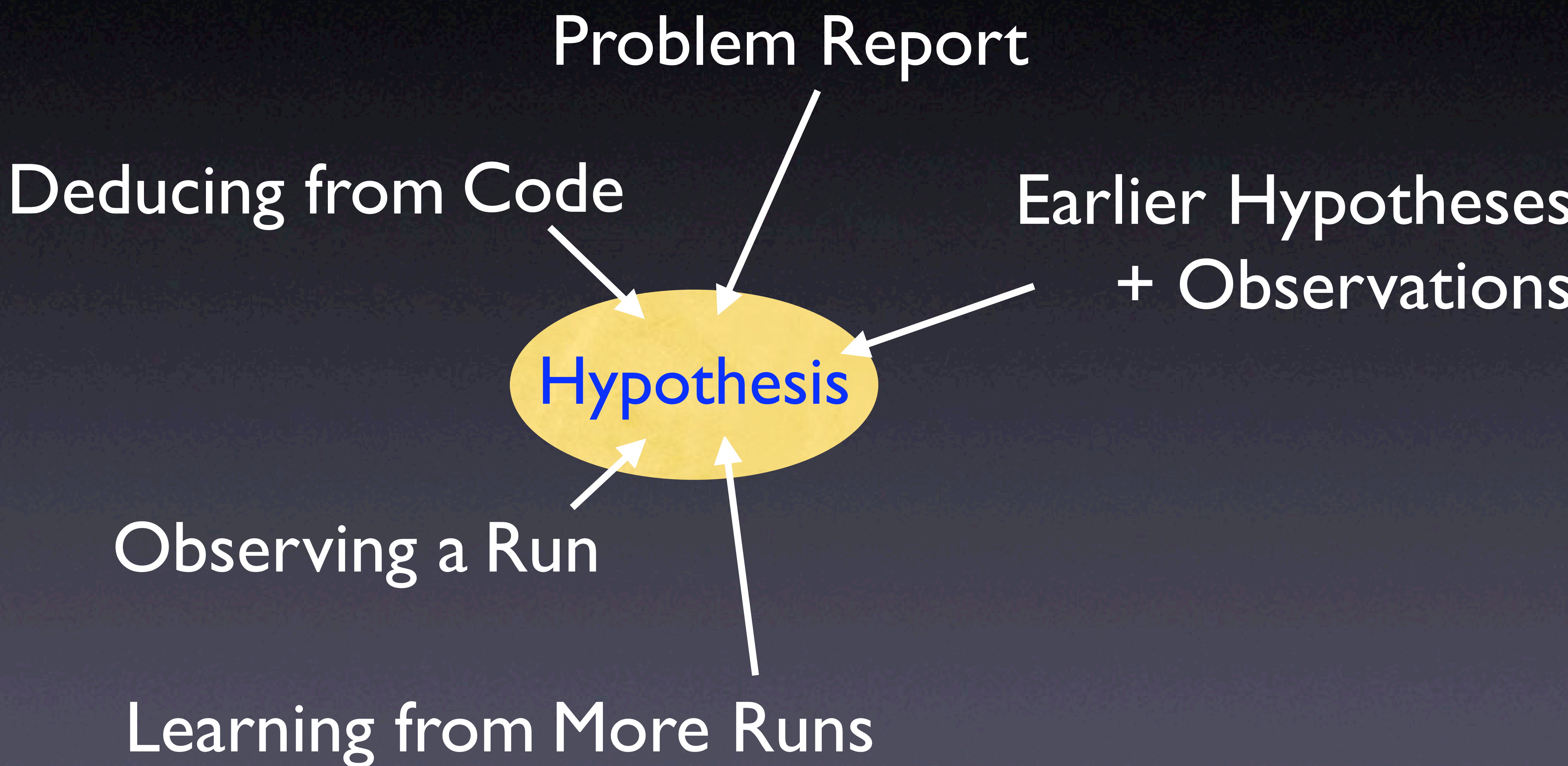
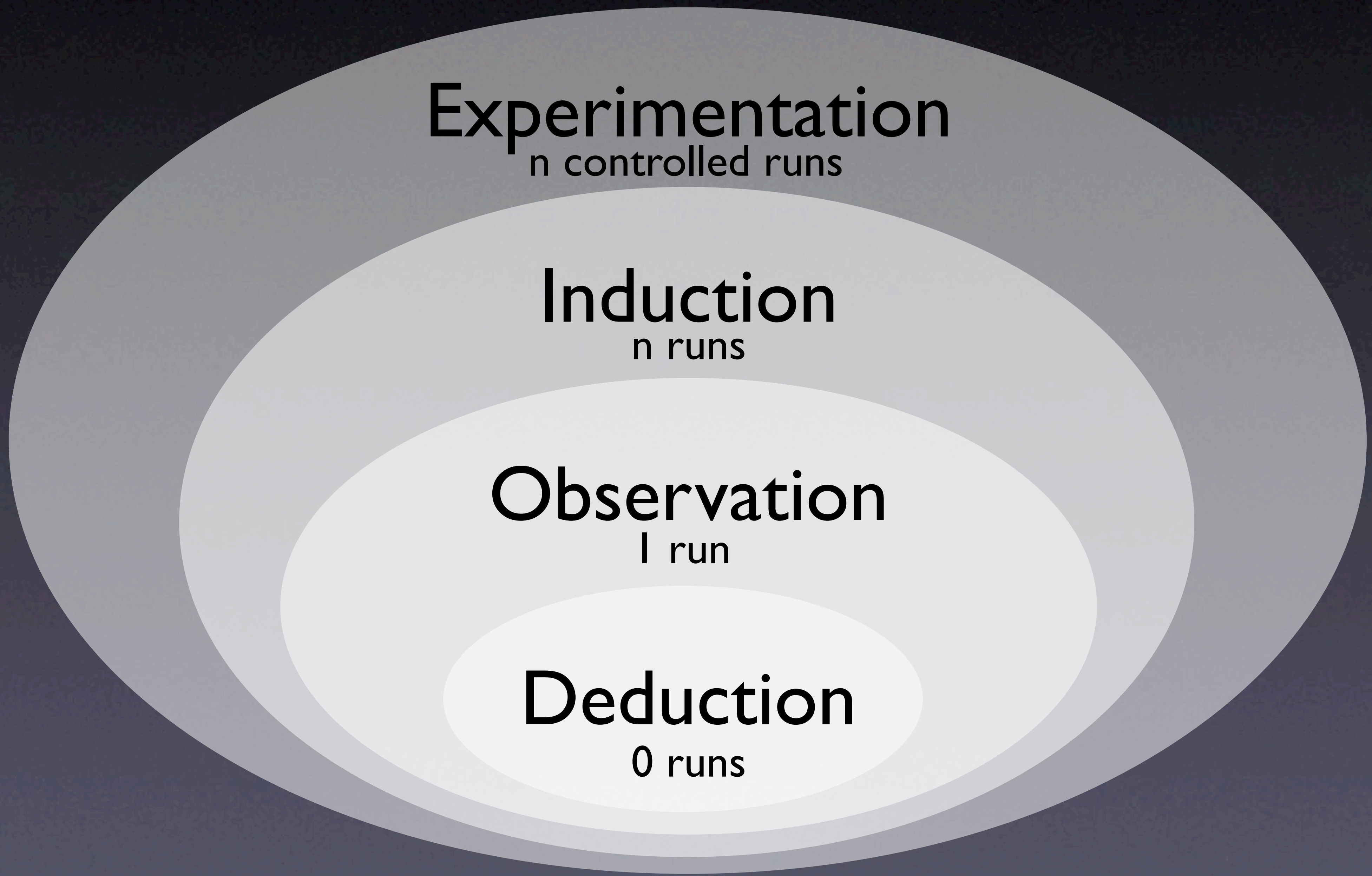
Obtaining a Hypothesis



Reasoning about Runs



Reasoning about Runs

Deduction
0 runs

What's relevant?

```
10 INPUT X
20 Y = 0
30 X = Y
40 PRINT "X = ", X
```

Fibonacci Numbers

$$fib(n) = \begin{cases} 1, & \text{for } n = 0 \lor n = 1 \\ fib(n-1) + fib(n-2), & \text{otherwise} \end{cases} .$$

1	1	2	3	5	8	13	21	34	55

fibo.c

```c
int fib(int n)
{
    int f, f0 = 1, f1 = 1;

    while (n > 1) {
      n = n - 1;
      f = f0 + f1;
      f0 = f1;
      f1 = f;
    }

    return f;
}
```

```c
int main()
{
  int n = 9;

  while (n > 0)
  {
    printf("fib(%d)=%d\n",
           n, fib(n));
    n = n - 1;
  }

    return 0;
}
```

Fibo in Action

```
$ gcc -o fibo fibo.c
$ ./fibo
fib(9)=55
fib(8)=34
...
fib(2)=2
fib(1)=134513905
```

Where does fib(1) come from?

Effects of Statements

- Write. A statement can change the program state (i.e. write to a variable)
- Control. A statement may determine which statement is executed next (other than unconditional transfer)

Affected Statements

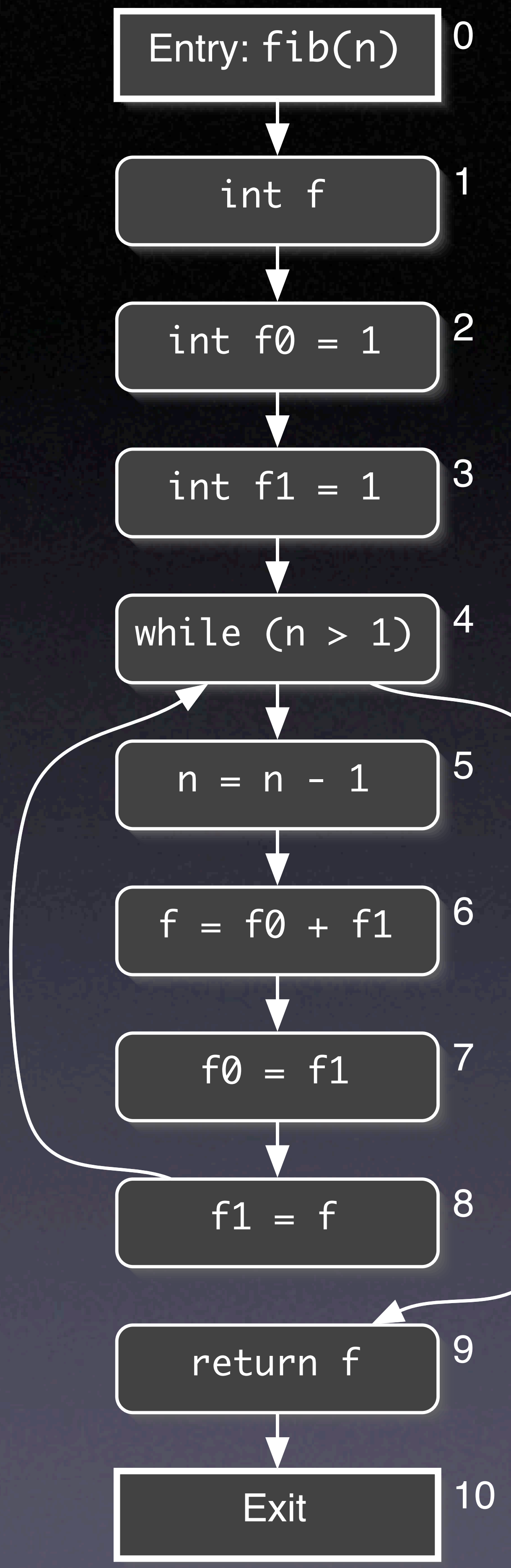
- Read. A statement can read the program state (i.e. from a variable)
- Execution. To have any effect, a statement must be executed.

Effects in fibo.c

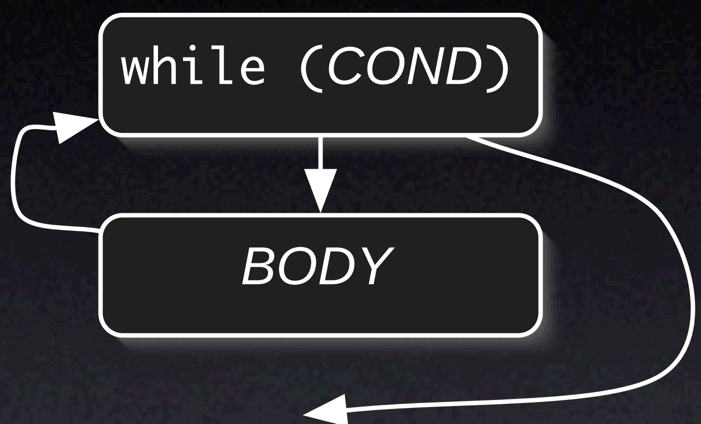
	Statement	Reads	Writes	Controls
0	fib(n)		n	1-10
1	int f		f	
2	f0 = 1		f0	
3	f1 = 1		f1	
4	while (n > 1)	n		5-8
5	n = n - 1	n	n	
6	f = f0 + f1	f0, f1	f	
7	f0 = f1	f1	f0	
8	f1 = f	f	f1	
9	return f	f	<ret>	

Control Flow

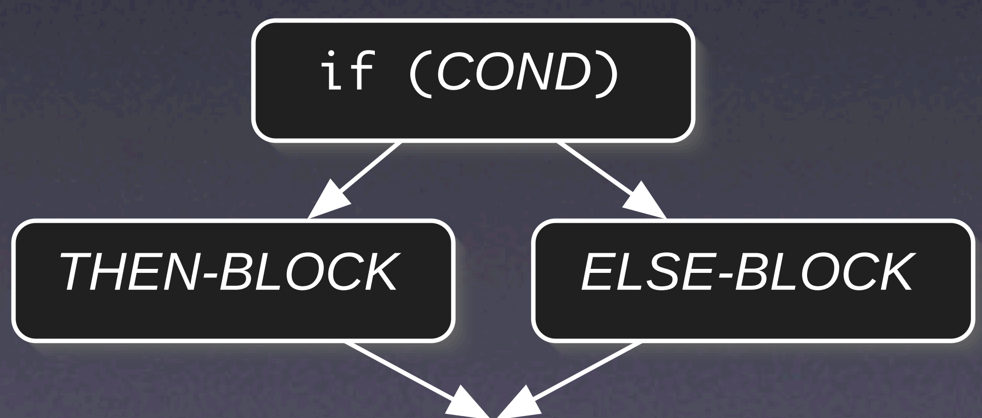
```
int fib(int n)
{
    int f, f0 = 1, f1 = 1;

    while (n > 1) {
      n = n - 1;
      f = f0 + f1;
      f0 = f1;
      f1 = f;
    }

    return f;
}
```



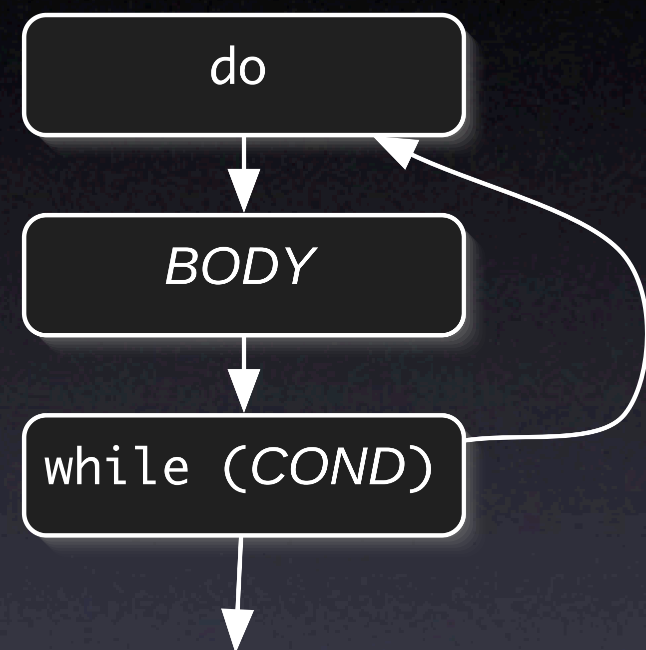
Control Flow Patterns



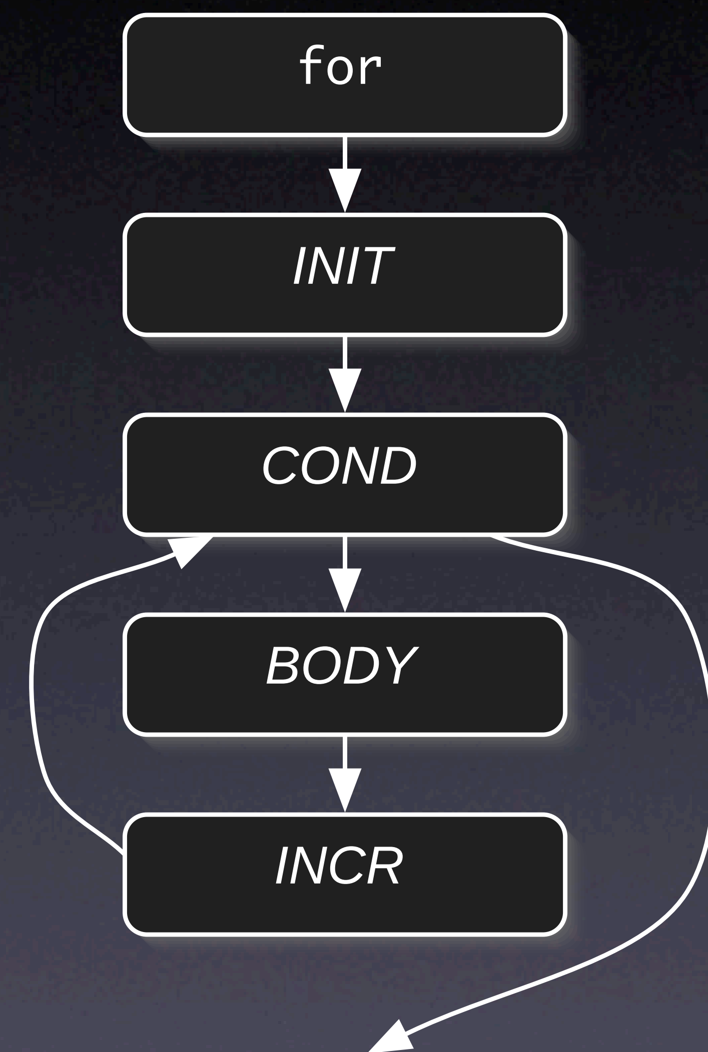

```
while (COND)
  BODY;
```




```
if (COND)
  THEN-BLOCK;
else
  ELSE-BLOCK;
```

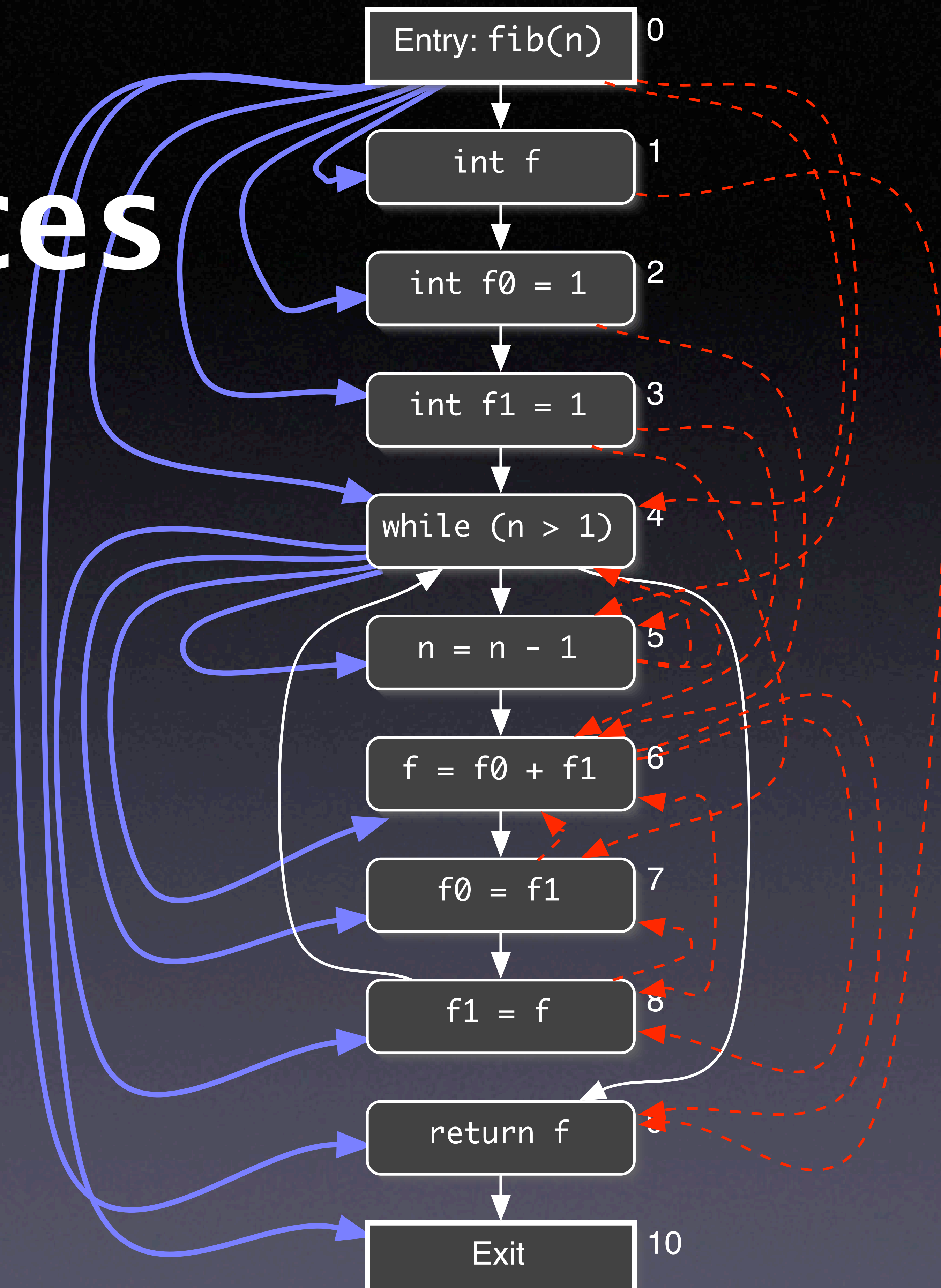



```
do {
      BODY
} while (COND);
```




```
for  (INIT; COND; INCR)
  BODY;
```

Dependences



A - - - -► B

Data dependency:

A's data is used in B;

B is data dependent on A

A · · · · ·► B

Control dependency:

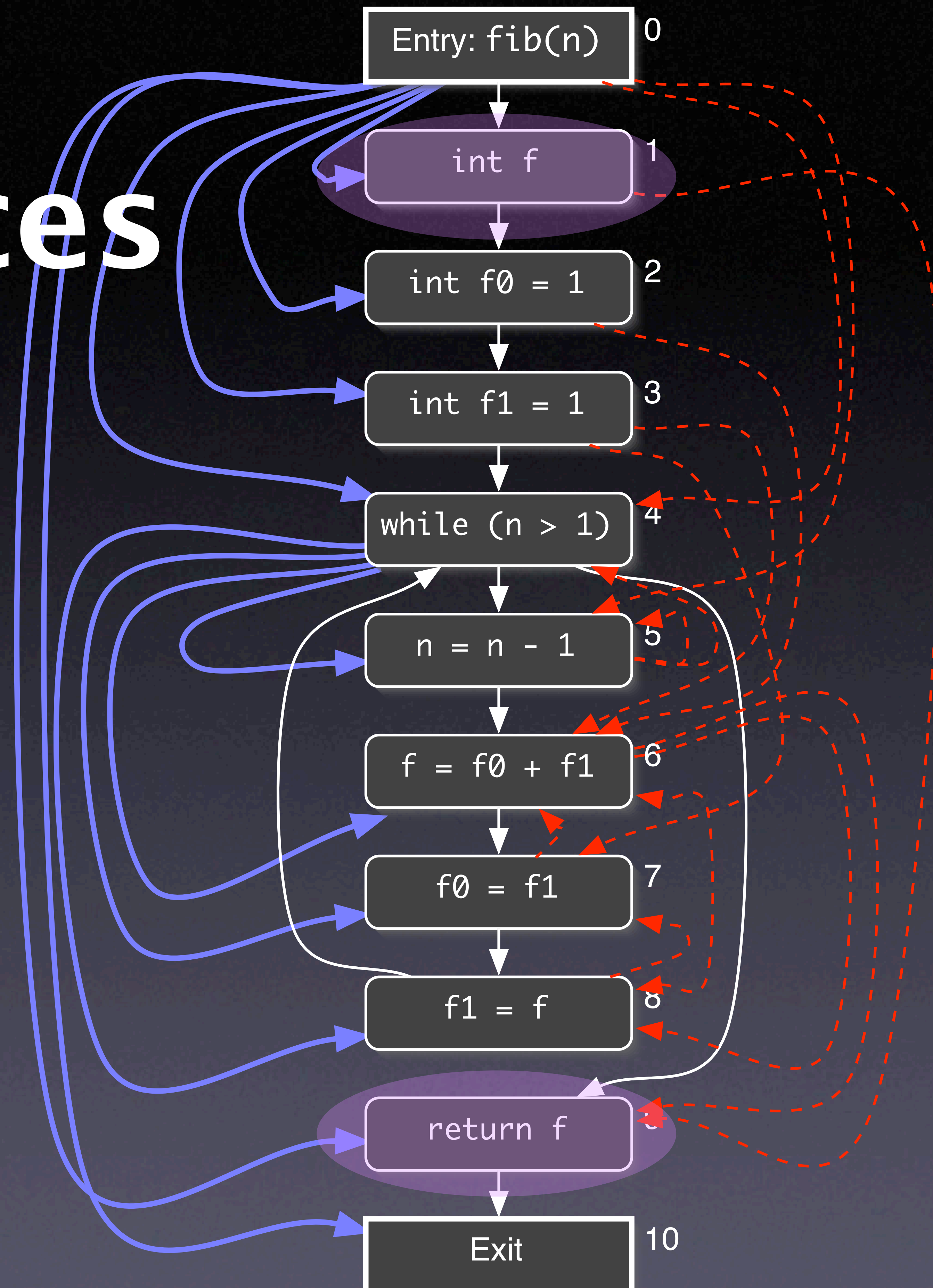
A controls B's execution;

B is control dependent on A

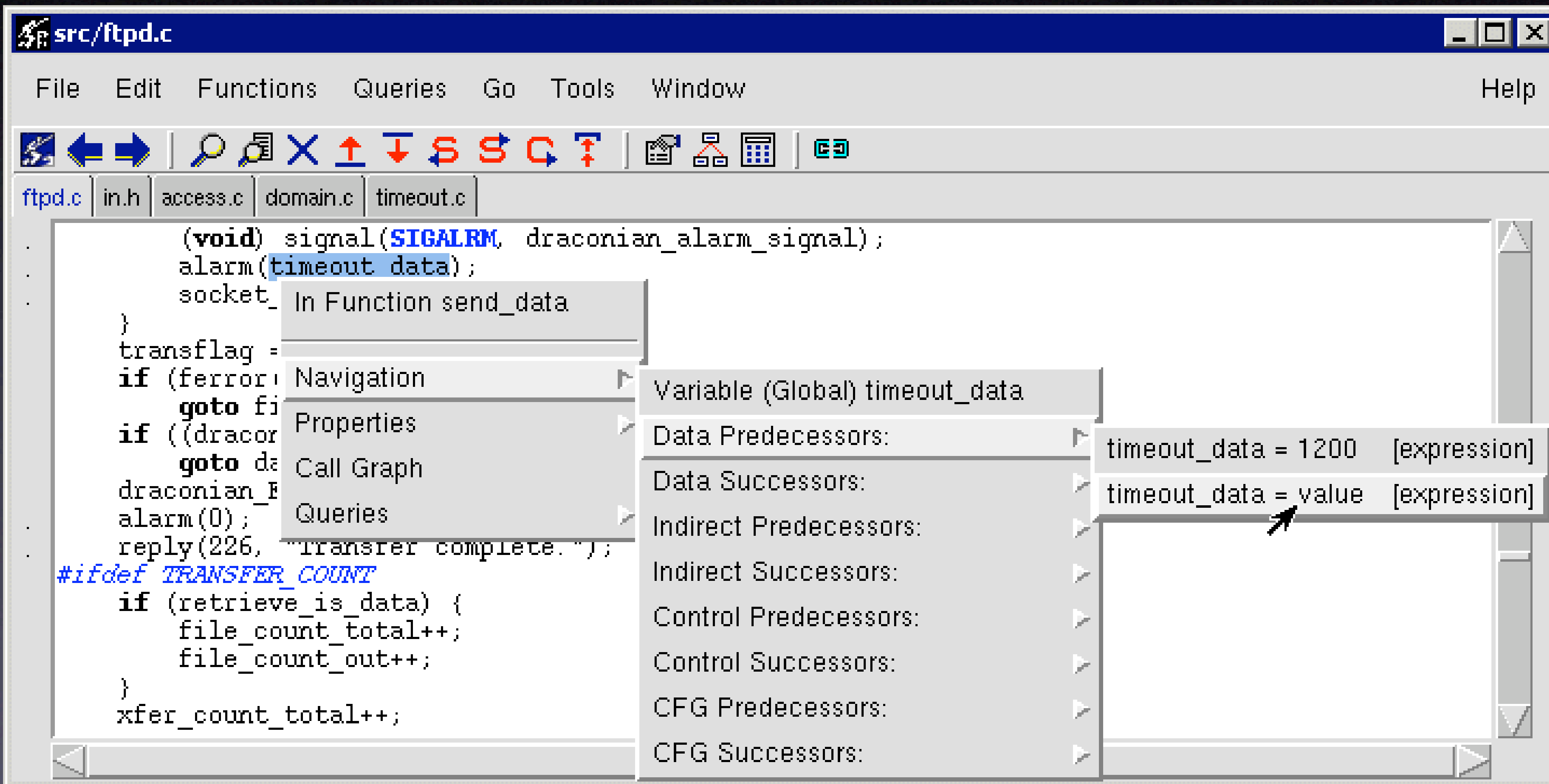
Dependences

Following the dependences, we can answer questions like

- Where does this value go to?
- Where does this value come from?



Navigating along Dependences

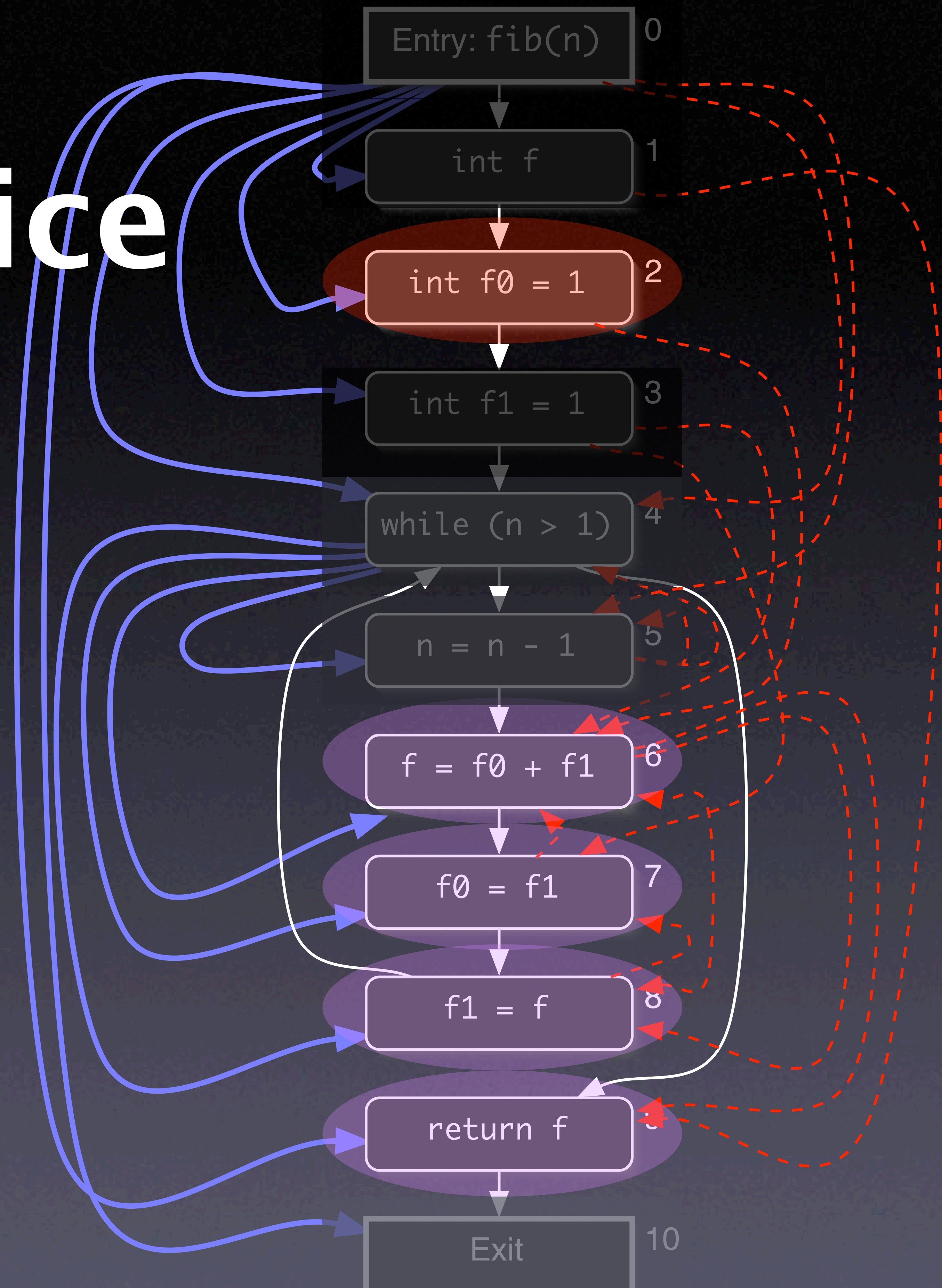


Program Slicing

- A *slice* is a subset of the program
- Allows programmers to *focus on what's relevant* with respect to some statement S:
  - All statements influenced by S
  - All statements that influence S

Forward Slice

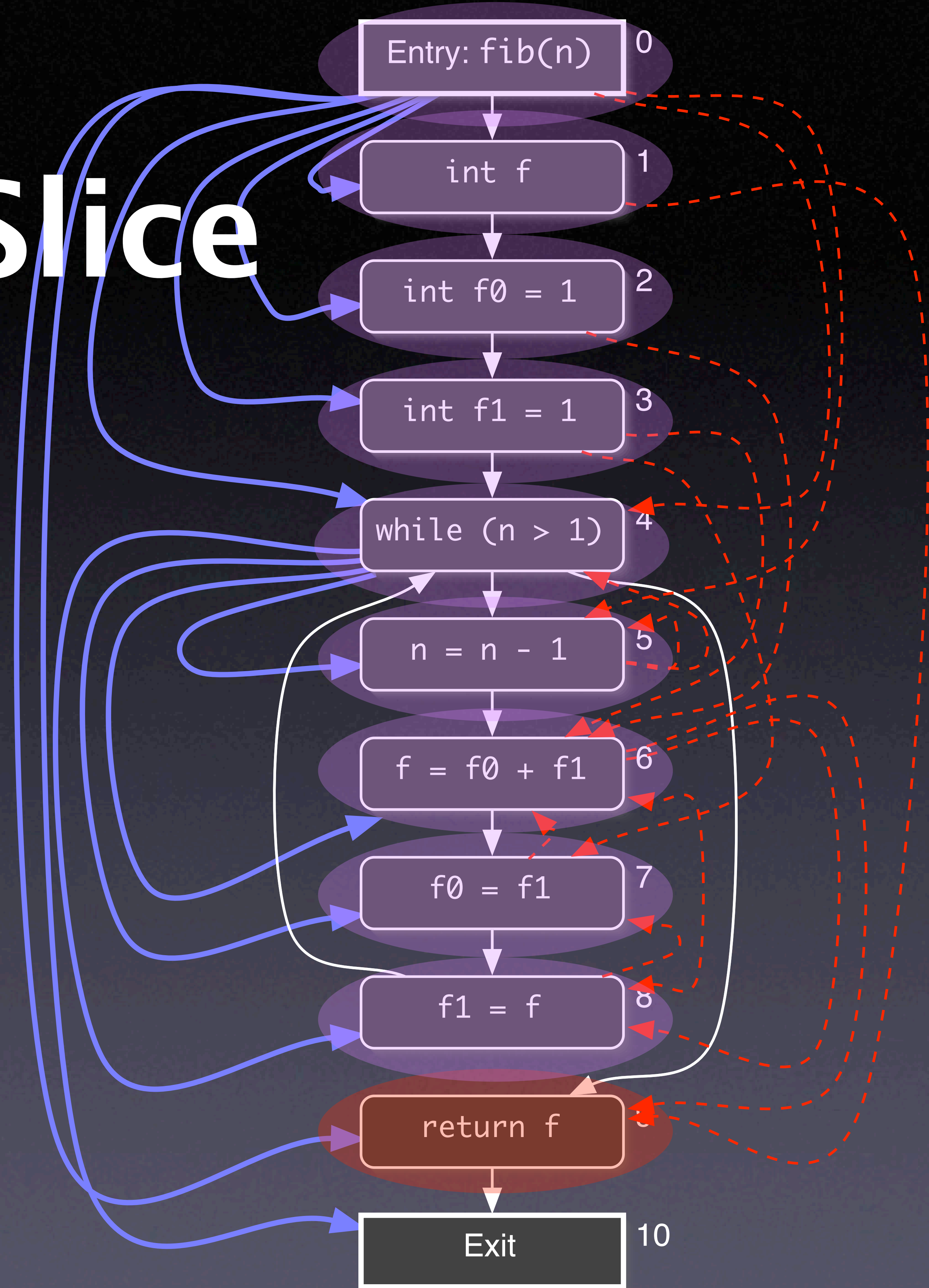
- Given a statement A, the forward slice contains all statements whose read variables or execution could be influenced by A
- Formally:
  $S^F(A) = \{B | A \to^* B\}$



Backward Slice

- Given a statement B, the backward slice contains all statements that could influence the read variables or execution of B
- Formally:

$$S^B(B) = \{A | A \rightarrow^* B\}$$



Two Slices

```
int main() {
  int a, b, sum, mul;
  sum = 0;
  mul = 1;
  a = read();
  b = read();
  while (a <= b) {
    sum = sum + a;
    mul = mul * a;
    a = a + 1;
  }
  write(sum);
  write(mul);
}
```

← Backward slice of sum

← Backward slice of mul

Slice Operations:

- Backbones
- Dices
- Chops

Backbone

```
a = read();
b = read();
while (a <= b) {


   a = a + 1;
```

- Contains only those statement that occur in both slices
- Useful for focusing on common behavior

Two Slices

```
int main() {
  int a, b, sum, mul;
  sum = 0;
  mul = 1;
  a = read();
  b = read();
  while (a <= b) {
    sum = sum + a;
    mul = mul * a;
    a = a + 1;
  }
  write(sum);
  write(mul);
}
```

Backward slice of sum

Backward slice of mul

Slice Operations:

- Backbones
- Dices
- Chops

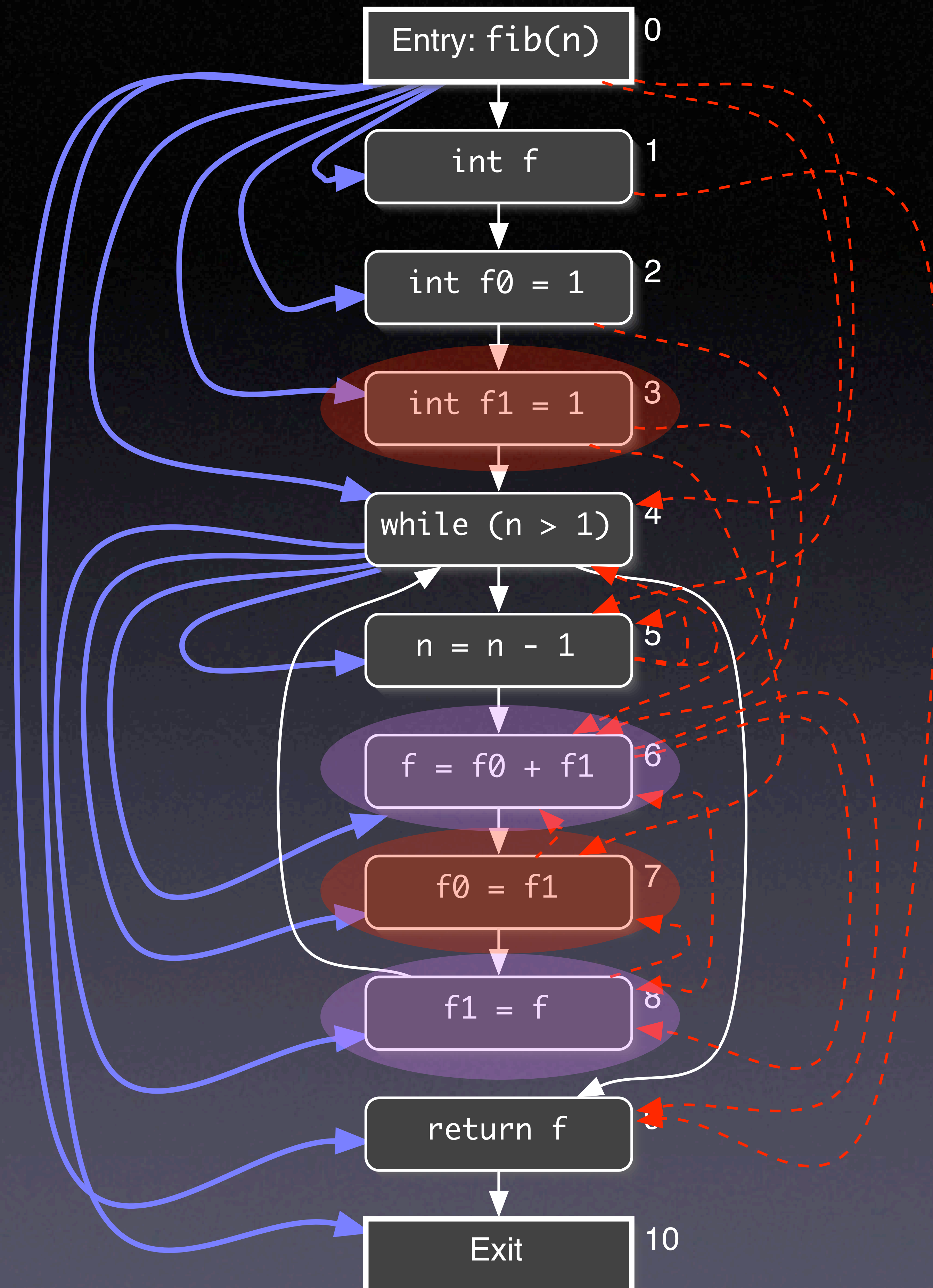
Dice

```
sum = 0;

  sum = sum + a;

write(sum);
```

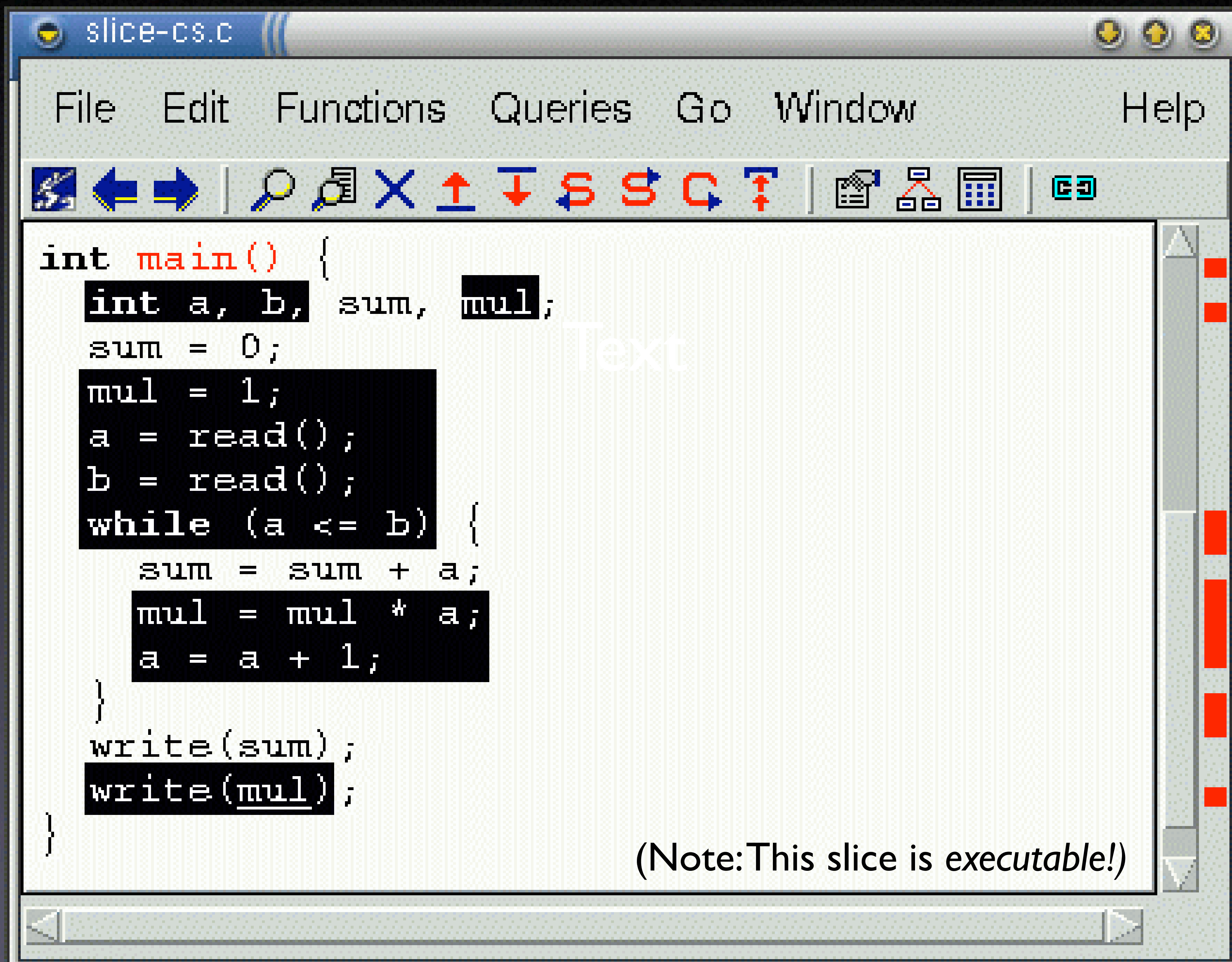
- Contains only the difference between two slices
- Useful for focusing on differing behavior

Chop

- Intersection between a forward and a backward slice
- Useful for determining influence paths within the program



Leveraging Slices



(Note: This slice is *executable!*)

Deducing Code Smells

- Use of uninitialized variables
- Unused values
- Unreachable code
- Memory leaks
- Interface misuse
- Null pointers

Uninitialized Variables

```
$ gcc -Wall -O -o fibo fibo.c
fibo.c: In function `fib':
fibo.c:7: warning: `f' might be
used uninitialized in this
function
```

False Positives

```
int go;
switch (color) {
    case RED:
    case AMBER:
        go = 0;
        break;
    case GREEN:
        go = 1;
        break;
}
if (go) { ... }
```

warning: `go' might be used uninitialized in this function

Unreachable Code

```
if (w >= 0)
    printf("w is non-negative\n");
else if (w > 0)
    printf("w is positive\n");
```

warning: will never be executed

Memory Leaks

```
int *readbuf(int size)
{
    int *p = malloc(size * sizeof(int));
    for (int i = 0; i < size; i++) {
        p[i] = readint();
        if (p[i] == 0)
            return 0;  // end-of-file
    }
    return p;
}
```

memory leak

Interface Misuse

```
void readfile()
{
    int fp = open(file);
    int size = readint(file);
    if (size <= 0)
        return;
    ...
    close(fp);
}
```

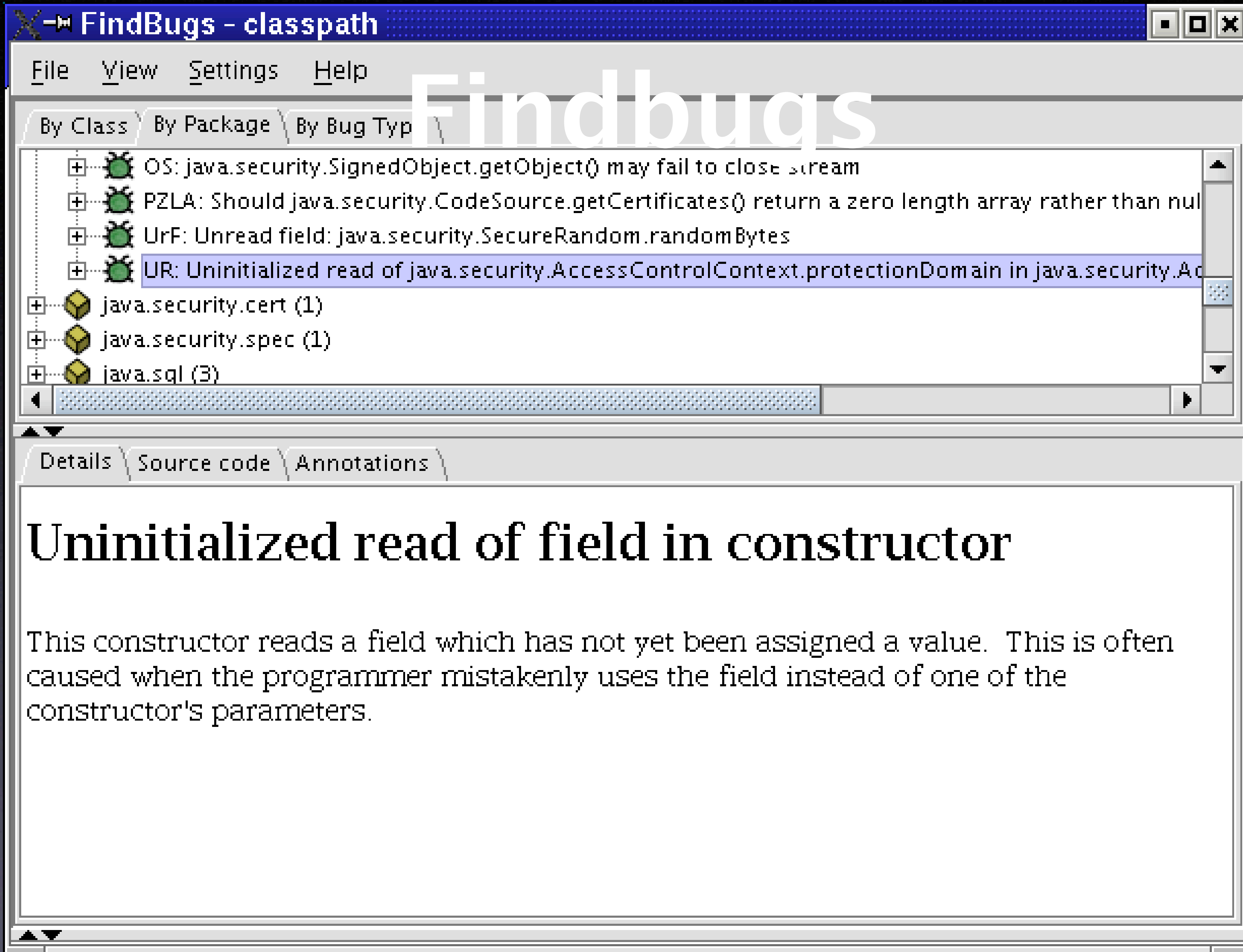
stream not closed

Null Pointers

```
int *readbuf(int size)
{
    int *p = malloc(size * sizeof(int));
    for (int i = 0; i < size; i++) {
        p[i] = readint();
        if (p[i] == 0)
            return 0;  // end-of-file
    }
    return p;
}
```

p may be null

Findbugs



FindBugs - classpath
File
View
Settings
Help
By Class
By Package
By Bug Typ
OS: java.security.SignedObject.getObject() may fail to close stream
PZLA: Should java.security.CodeSource.getCertificates() return a zero length array rather than nul
UrF: Unread field: java.security.SecureRandom.randomBytes
UR: Uninitialized read of java.security.AccessControlContext.protectionDomain in java.security.Ac
java.security.cert (1)
java.security.spec (1)
java.sql (3)
Details
Source code
Annotations
Uninitialized read of field in constructor
This constructor reads a field which has not yet been assigned a value. This is often caused when the programmer mistakenly uses the field instead of one of the constructor's parameters.

Defect Patterns

- Class implements `Cloneable` but does not define or use `clone` method
- Method might ignore exception
- Null pointer dereference in method
- Class defines `equal()`; should it be `equals()`?
- Method may fail to close database resource
- Method may fail to close stream
- Method ignores return value
- Unread field
- Unused field
- Unwritten field

Limits of Analysis

```
int x;
for(i=j=k=1;--j||k;k=j?i%j?k:k-j:(j=i+=2));
write(x);
```

- Is x being used uninitialized or not?
- Loop halts only if there is an odd perfect number (= a number that's the sum of its proper positive divisors)
- Problem is undediced yet

```
static void shell_sort(int a[], int size)
{
    int i, j;
    int h = 1;
    do {
        h = h * 3 + 1;
    } while (h <= size);
    do {
        h /= 3;
        for (i = h; i < size; i++)
        {
            int v = a[i];
            for (j = i; j >= h && a[j - h] > v; j -= h)
                a[j] = a[j - h];
            if (i != j)
                a[j] = v;
        }
    } while (h != 1);
}
```

Conservative approximation:
any a[] depends on all a[]

Causes of Imprecision

- Indirect access, as in a[i]
- Pointers
- Functions
- Dynamic dispatch
- Concurrency

Risks of Deduction

- Code mismatch. Is the run created from this very source code?
- Abstracting away. Failures may be caused by a defect in the environment.
- Imprecision. A slice typically encompasses 90% of the source code.

Increasing Precision

- Verification. If we know that certain properties hold, we can leverage them in our inference process.
- Observation. Facts from concrete runscan be combined with deduction.

…in the weeks to come!

Concepts

- To reason about programs, use
  - deduction (0 runs)
  - observation (1 run)
  - induction (multiple runs)
  - experimentation (controlled runs)

Concepts (2)

- To isolate value origins, follow back the dependences
- Dependences can uncover *code smells* such as
  - uninitialized variables
  - unused values
  - unreachable code
- Get rid of smells before debugging

Concepts (3)

- To slice a program, follow dependences from a statement S to find all statements that
  - could be influenced by S (forward slice)
  - could influence S (backward slice)

Concepts (4)

- Using deduction alone includes a number of risks, including code mismatch, sbstracting away, and imprecision.
- Any deduction is limited by the halting problem and must thus resort to conservative approximation.
- For debugging, deduction is best combined with actual observation.