Static Slicing of Binary Executables with DynInst

Tuğrul İnce

Slicing

```
int method=SET;
int number = 0;
int x = 1, y = 2;
if(method == SET) {
    number = 42;
    printf(“Just set the number to 42”);
}
else {
    x = y = 4;
    printf(“Not setting variable number”);
}
printf(“Final Value %d\n“, number);
```

Motivation

- Slicing is historically used for:
  - Debugging
  - Software Maintenance
  - Parallelization
- Generally on the source code
- Binary executables
  - Moving dynamic analysis to static
    - Function pointers
  - Improve code generation
  - Identifying malicious code
  - Reverse-engineering viruses
  - Binary Profilers

Slicing

- Weiser's original definition
  - identifying all program code that can in any way affect the value of a given variable
  - This is now called "static backward slicing"
- Static Forward Slicing
  - Identifying all statements and control predicates dependent on the variable in the slicing criterion
- Dynamic Slicing
  - Identifying program code that *actually* changes the value of a given variable, determined at runtime.

How to Determine a Slice

- Construct a *Program Dependence Graph*
  - A Combination of *Data Dependency Graph* and *Control Dependency Graph*
- Identify Data Dependency

```
a:=3
b:=a
```

➡ b *depends on* a

- Identify Control Dependency

```
if a=true then
    b:=1
else
    c:=0
```

➡ Both assignments *depend on* if statement

How to Determine a Slice

```
int main() {
  register int k=0;
  register int i=0;
  register int j=0;

  if(i==0) {
    k=1;
    j=5-k;
  }
  else {
    k=7;
    j=k-5;
  }
  i=k;
  printf("Printing i, j and k
     %d\n",
        i, j , k);
  return 0;
}
```

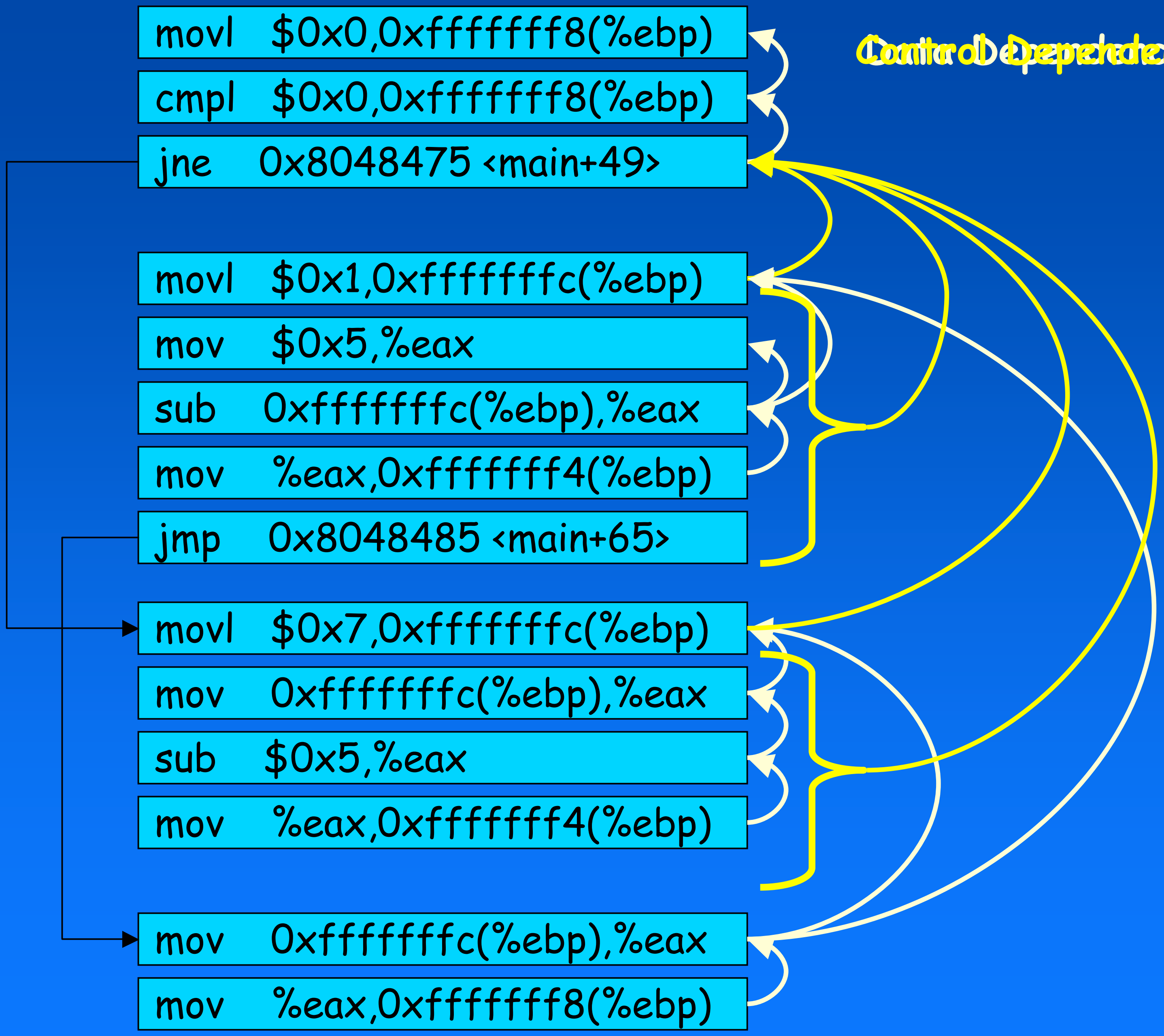
```
<main+9>:   mov    $0x0,%eax
<main+14>:  sub    %eax,%esp
<main+16>:  movl   $0x0,0xfffffff8(%ebp)
<main+23>:  cmpl   $0x0,0xfffffff8(%ebp)
```

```
<main+16>:  movl   $0x0,0xfffffff8(%ebp)
<main+23>:  cmpl   $0x0,0xfffffff8(%ebp)
<main+27>:  jne    0x8048475 <main+49>
<main+29>:  movl   $0x1,0xfffffffc(%ebp)
<main+36>:  mov    $0x5,%eax
<main+41>:  sub    0xfffffffc(%ebp),%eax
<main+44>:  mov    %eax,0xfffffff4(%ebp)
<main+47>:  jmp    0x8048485 <main+65>
<main+49>:  movl   $0x7,0xfffffffc(%ebp)
<main+56>:  mov    0xfffffffc(%ebp),%eax
<main+59>:  sub    $0x5,%eax
<main+62>:  mov    %eax,0xfffffff4(%ebp)
<main+65>:  mov    0xfffffffc(%ebp),%eax
<main+68>:  mov    %eax,0xfffffff8(%ebp)
```

```
<main+99>:  call   0x8048368 <printf@plt>
```

Control Dependence Graph

Data Dependence Graph

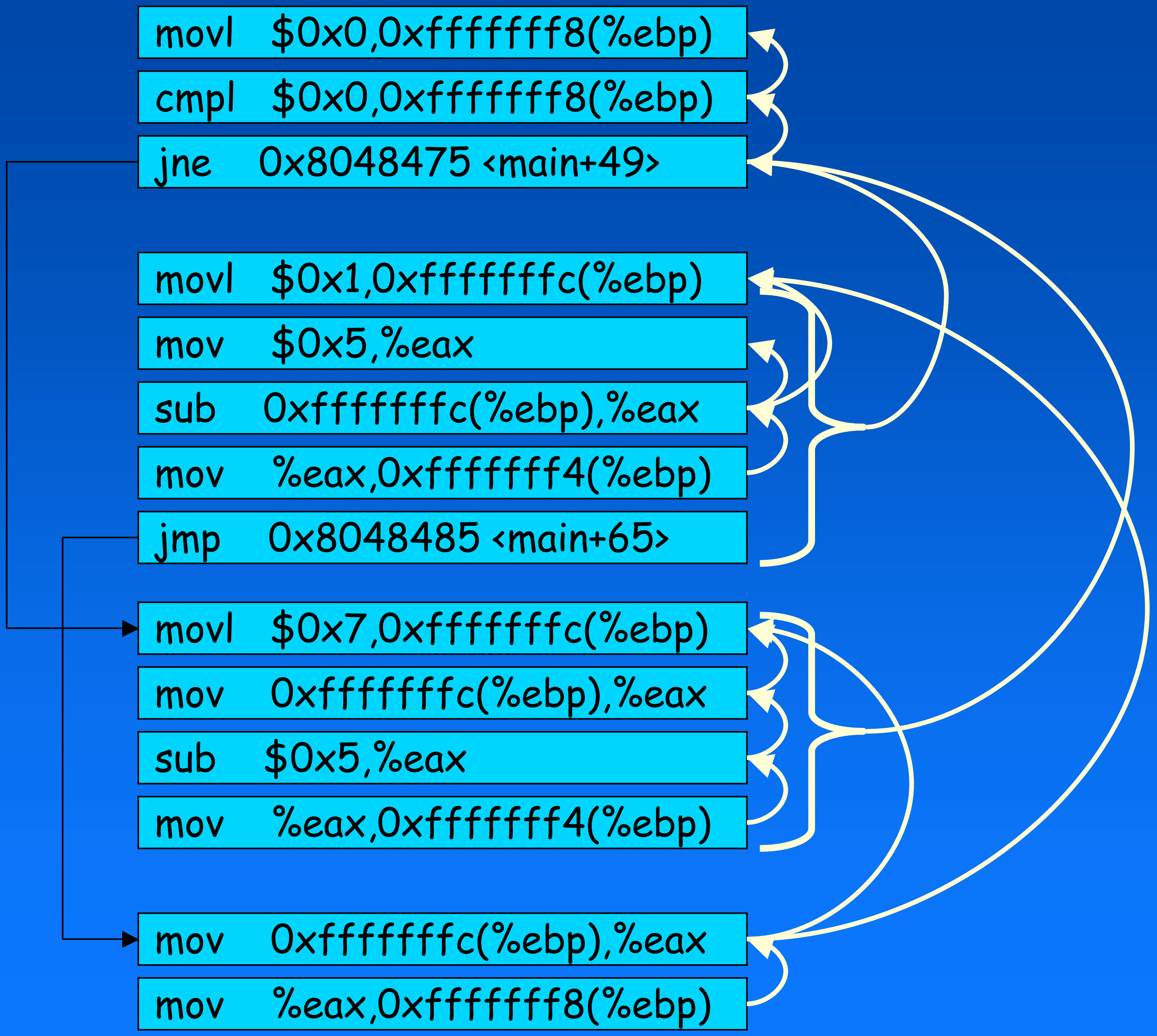


```
movl   $0x0,0xfffffff8(%ebp)
cmpl   $0x0,0xfffffff8(%ebp)
jne    0x8048475 <main+49>

movl   $0x1,0xfffffffc(%ebp)
mov    $0x5,%eax
sub    0xfffffffc(%ebp),%eax
mov    %eax,0xfffffff4(%ebp)
jmp    0x8048485 <main+65>

movl   $0x7,0xfffffffc(%ebp)
mov    0xfffffffc(%ebp),%eax
sub    $0x5,%eax
mov    %eax,0xfffffff4(%ebp)

mov    0xfffffffc(%ebp),%eax
mov    %eax,0xfffffff8(%ebp)
```



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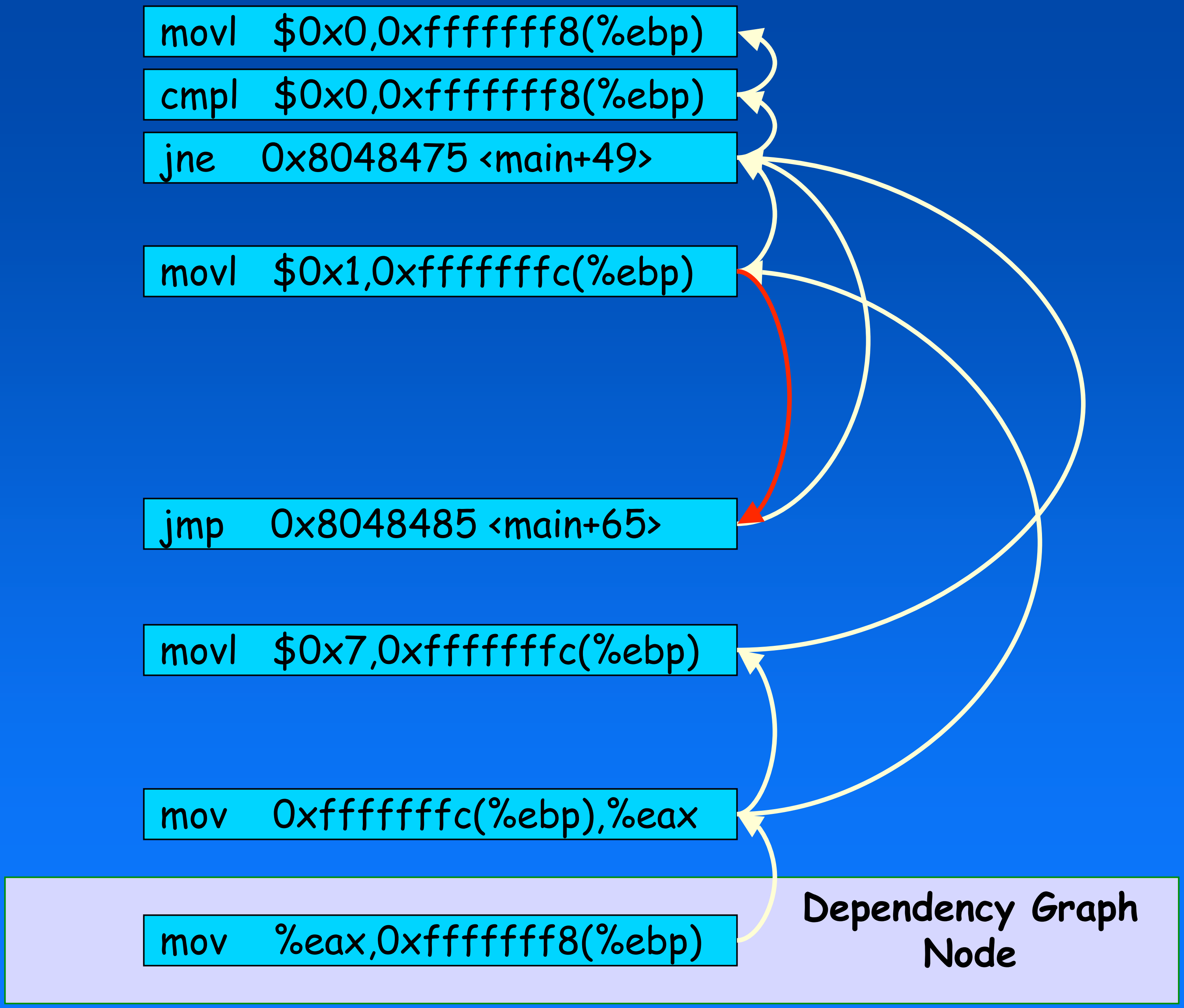
movl  $0x0,0xfffffff8(%ebp)
cmpl  $0x0,0xfffffff8(%ebp)
jne   0x8048475 <main+49>

movl  $0x1,0xfffffffc(%ebp)
mov   $0x5,%eax
sub   0xfffffffc(%ebp),%eax
mov   %eax,0xfffffff4(%ebp)
jmp   0x8048485 <main+65>

movl  $0x7,0xfffffffc(%ebp)
mov   0xfffffffc(%ebp),%eax
sub   $0x5,%eax
mov   %eax,0xfffffff4(%ebp)

mov   0xfffffffc(%ebp),%eax
mov   %eax,0xfffffff8(%ebp)
```



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movl   $0x0,0xfffffff8(%ebp)
cmpl   $0x0,0xfffffff8(%ebp)
jne    0x8048475 <main+49>
movl   $0x1,0xfffffffc(%ebp)
jmp    0x8048485 <main+65>
movl   $0x7,0xfffffffc(%ebp)
mov    0xfffffffc(%ebp),%eax
mov    %eax,0xfffffff8(%ebp)
```

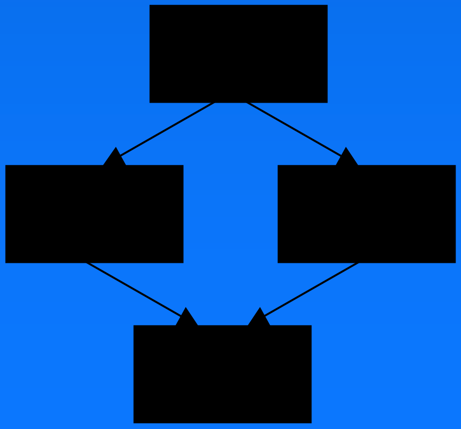
Implementation

- Static Analysis
  - DynInst loads executable in stopped state
- Building Data Dependency Graph
  - For each instruction in a basic block, determine registers/variables that are read/written
    - Not so easy, large instruction set
  - When an instruction reads a register/variable, mark it as dependent on the one that recently modified that reg/var

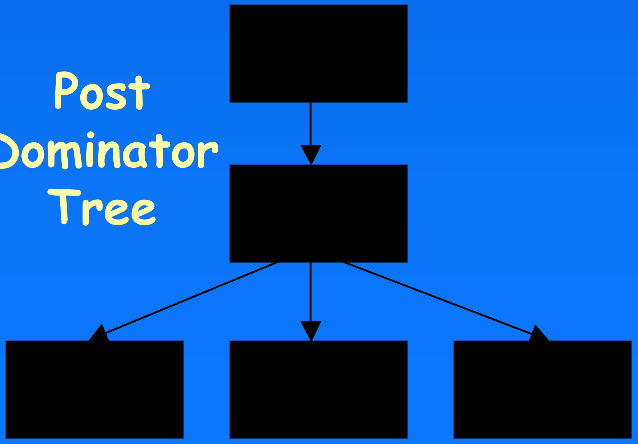
Building Control Dependency Graph

- A node V is post-dominated by a node W if every directed path from V to Stop contains W
- An instruction Y is control dependent on another instruction X iff
  - There exists a directed path P from X to Y with another instruction Z in P, post-dominated by Y
  - X is not post-dominated by Y

CFG



Post Dominator Tree



Challenges

- Indirect Jump Instructions
  - Hard to create control flow graph
  - Very common in switch statements
    - Follows a pattern
- Aliasing
  - Currently not handled
  - Pointers
  - Treat all memory as a single object
    - Overly Conservative
    - EEL's approach

On-demand Computation

- Generation of Data and Control Dependency Graph is costly, so is Slicing
- Since it is static, it is enough to compute these graphs only once
- Therefore, they are computed only on-demand and stored until the execution finishes

Annotation Framework

- Many analyses generate data while examining instructions/functions etc.
  - Generally costly operations
    - Store the result !
- New analysis means new variable(s) added to class definition
  - Error prone
  - API changes
  - Requires rebuild

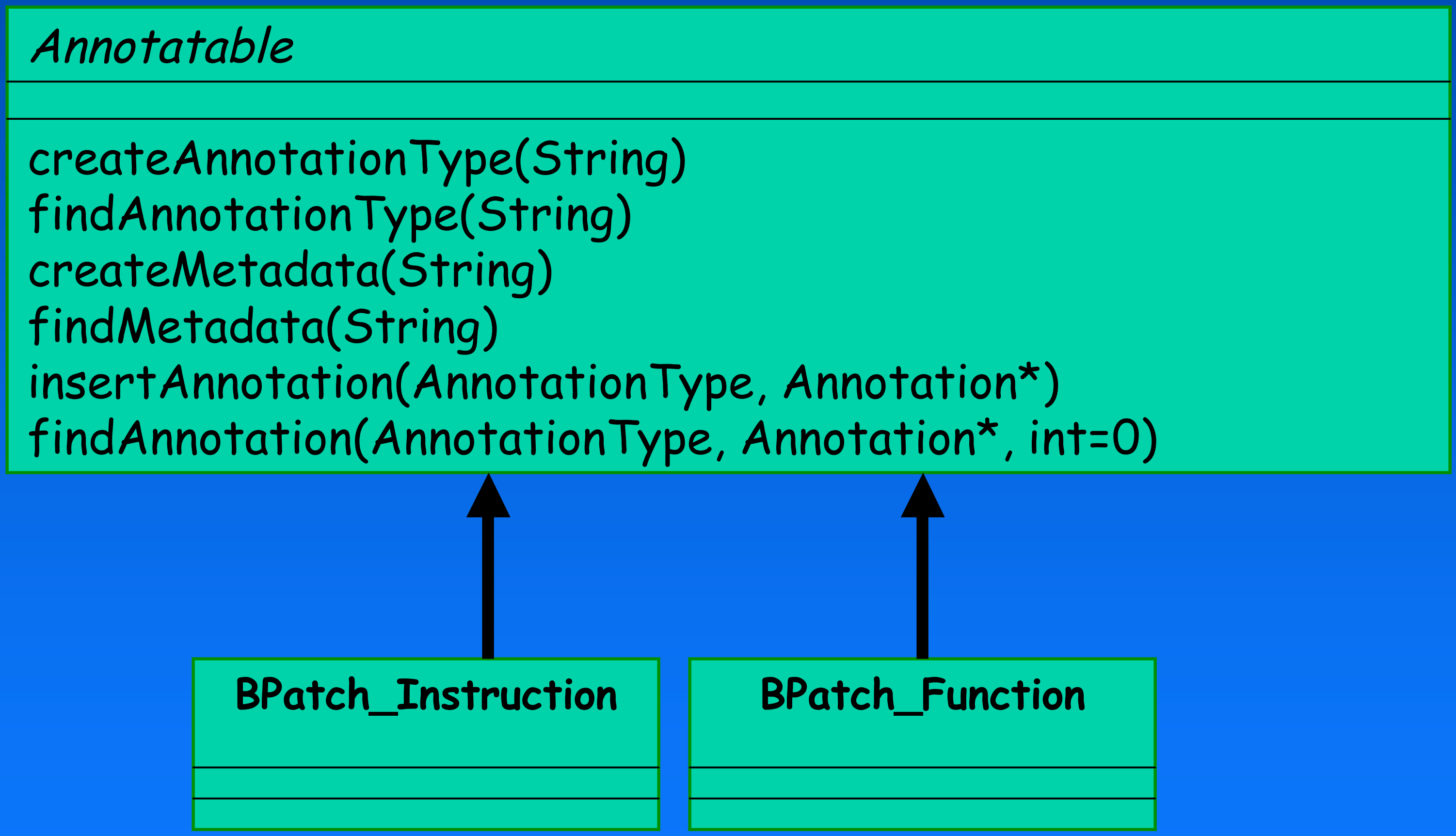
Annotation Framework

- Create a unified Annotation Framework instead
- Use a well-defined interface for each object that needs to be annotated
- Has to be extensible
  - Add new annotation types at runtime
- Support for storing metadata along with data

Annotation Framework Example

- Requires development effort
- Not desirable
  - Error-prone
  - Tedious

Annotation Framework



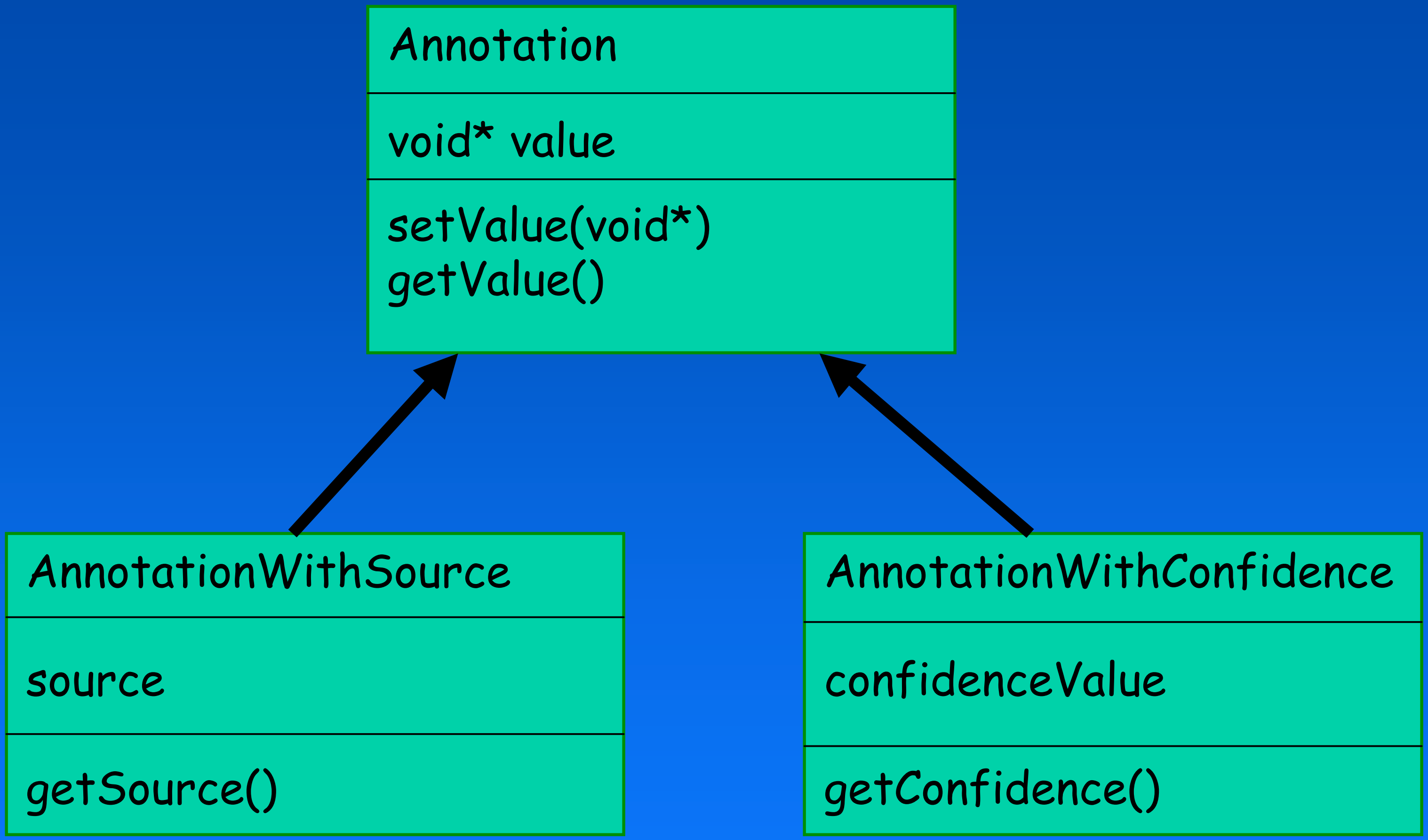
Annotatable

createAnnotationType(String)
findAnnotationType(String)
createMetadata(String)
findMetadata(String)
insertAnnotation(AnnotationType, Annotation*)
findAnnotation(AnnotationType, Annotation*, int=0)

BPatch_Instruction

BPatch_Function

Annotation Framework



Annotation

void* value

setValue(void*)
getValue()

AnnotationWithSource

source

getSource()

AnnotationWithConfidence

confidenceValue

getConfidence()

Example

```
BPatch_function function = … ;
AnnotationType type =
   function.createAnnotationType(“Slice”);
Graph* slicingGraph = … ;
function.insertAnnotation(type,
   new Annotation(slicingGraph));
……
function.findAnnotation(type,fillMe);
```

Summary

- Slicing
  - Status
    - Intra-procedural Slicing implemented for x86 Linux and Solaris 2.9
    - Inter-procedural Slicing is on the way
  - Aliasing not supported yet
- Annotation Framework
  - Status: Designed, at implementation stage
  - Unifies the way objects are annotated
  - Slicing will be the first user