Sample "Optimizations"

Constant propagation and folding

```
a = 1;
b = 2;
c = a + b;
```

```
c = 3;
```

Common subexpression elimination

```
a = b + c;
d = b + c;
```

```
a = b + c;
d = a;
```

Unreachable code elimination

```
if(DEBUG)
System.out.println("");
```

```

```

Sample "Optimizations"

Arithmetic optimizations

```
x = y * 1;
i = j + j;
a = b*c + b*d;
```

```
x = y;
i = j << 1;
a = b*(c + d);
```

Loop-invariant code motion

```
for(i = 0; i < a.length - foo; i++) {
    sum += a[i];
}
```

```
l = a.length - foo;
for(i = 0; i < l; i++) {
    sum += a[i];
}
```

Sample “Optimizations”

Check elimination

```
for(i = 0; i < 10; i++) {
    if(a == null) throw new Exception();
    if(i<0 || i>=a.length) throw new Exception();
    a[i] = i;
}
```

```
for(i = 0; i < 10; i++) {
    a[i] = i;
}
```

No Optimal Compiler (Appel, p. 350)

Full Employment Theorem for Compiler Writers

No compiler produces optimal correct code for all programs.
For every compiler A, there exists a better compiler B.

So, "optimizing" compiler really means (hopefully) improving compiler.

“Optimizations” can hurt performance

```
a = b + c;

d = b + c;
```

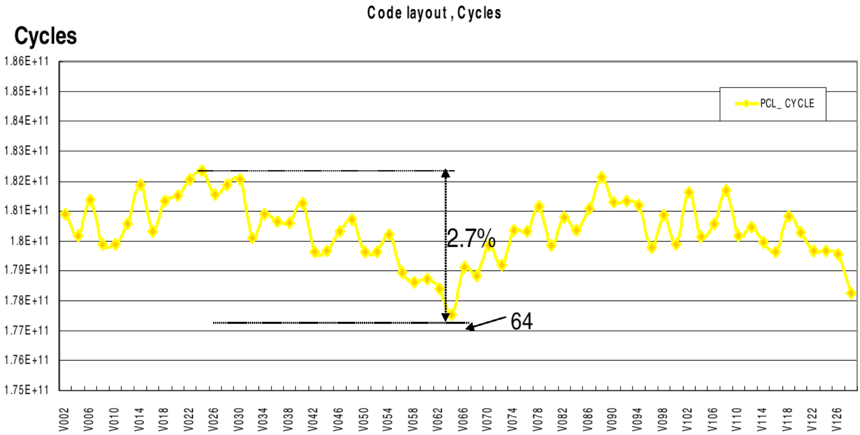
```
a = b + c;

d = a;
```

“Optimizations” can hurt performance

```
a = b + c;
// expensive computation requiring many registers
d = b + c;
```

```
a = b + c;
// expensive computation requiring many registers
d = a;
```

Hardware performance can be hard to model



Gu, Verbrugge, Gagnon, Code Layout as a Source of Noise in JVM Performance, Component And Middleware Performance Workshop, OOPSLA 2004

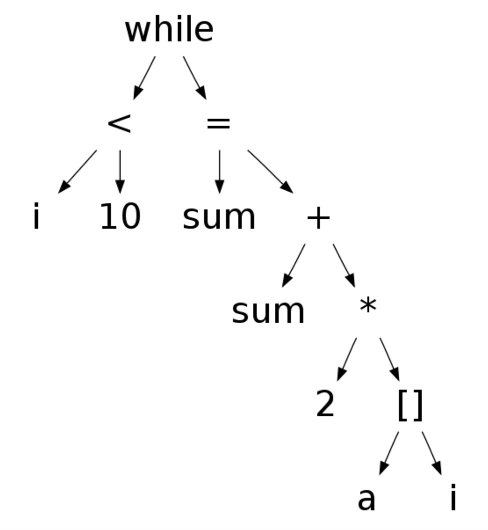
An “optimization” should be...

- semantics-preserving (“safe”)
- profitable
- widely applicable
- cheap to perform
    - compilation time
    - memory requirements
    - implementation complexity

Intermediate representations

```
while(i<10) { sum = sum + 2*a[i]; }
```

Abstract syntax tree:



Intermediate representations

```
while(i<10) { sum = sum + 2*a[i]; }
```

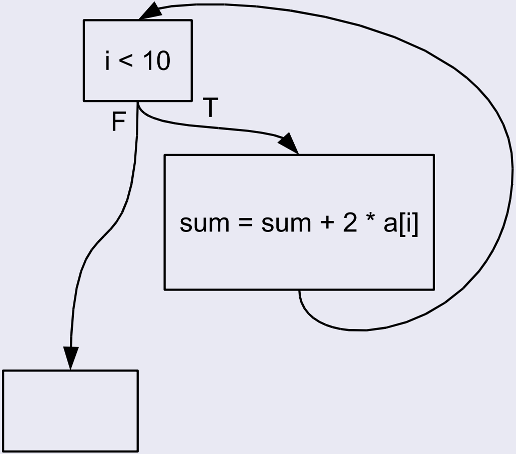
Three-address code sequence:

```
L0:
t1 = i >= 10;
if t1 goto L1;
t2 = i * 4;
t3 = a + t2;
t4 = *t3;
t5 = 2 * t4;
sum = sum + t5;
goto L0;
L1:
```

Intermediate representations

```
while(i<10) { sum = sum + 2*a[i]; }
```

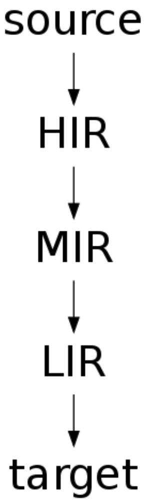
Control-flow graph:



Intermediate representations

High-level	$\leftrightarrow$	Low-level
language-specific	$\leftrightarrow$	language-independent
machine-independent	$\leftrightarrow$	machine-specific
tree/graph	$\leftrightarrow$	instruction sequence
structured control flow	$\leftrightarrow$	gotos
compound expressions	$\leftrightarrow$	simple expressions
high-level constructs	$\leftrightarrow$	constructs expanded

Intermediate representations



A question to ponder...

Q1: What is the output of this program?

```
System.out.println("Hello, World!");
```

A question to ponder...

Q1: What is the output of this program?

```
System.out.println("Hello, World!");
```

Q2: Given an arbitrary program p, can you tell whether its output is "Hello, World!"?

Does this program print “Hello, World!”?

```
if( arbitraryComputation() ) {
    System.out.println("Hello, World!");
} else {
    System.out.println("Goodbye");
}
```

Does this program cause an array overflow?

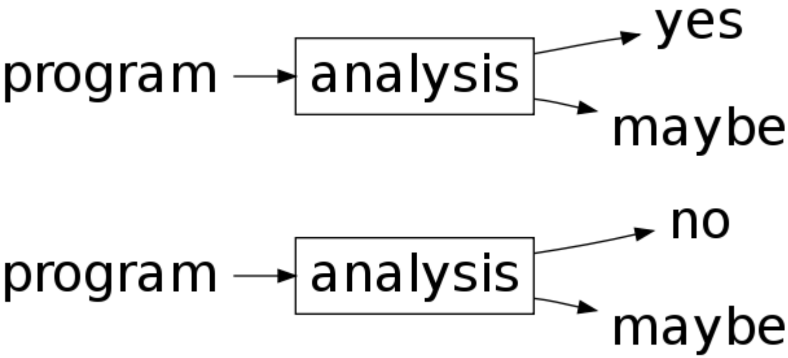
```
if( arbitraryComputation() ) {
    int a[] = new int[5];
    a[10] = 10;
}
```

Rice's Theorem

For any interesting property *Pr* of the behaviour of a program, it is impossible to write an analysis that can decide for every program p whether *Pr* holds for p.

Static Analysis

We settle for static analyses that approximate a property Pr.
Example: Does program p access an array out of bounds?



It's always safe to say "maybe"!

Static Analysis

Sound

An analysis is sound if its **result includes every possible behaviour** (but may include additional behaviours).

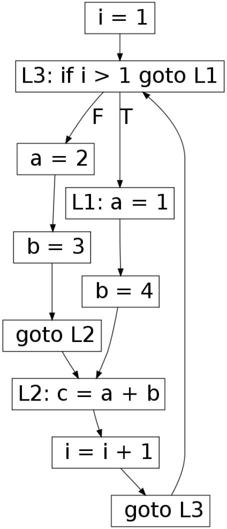
Conservative

An analysis is conservative if its result includes every possible behaviour (**but may include additional behaviours**).

Code Example

```
    i = 1
L3: if i > 1 goto L1
    a = 2
    b = 3
    goto L2
L1: a = 1
    b = 4
L2: c = a + b
    i = i + 1
    goto L3
```

Control Flow Graph



Basic Block Graph