CMPEN 431
Computer Architecture
Fall 2017

Understanding Program Dependencies

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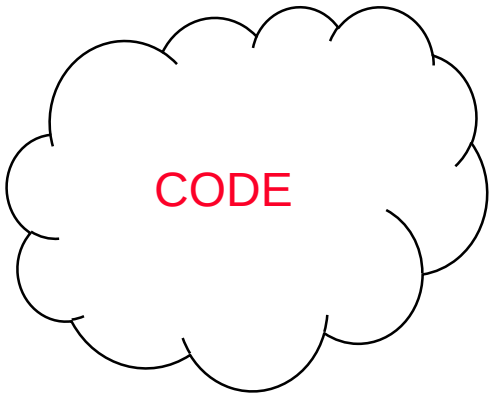
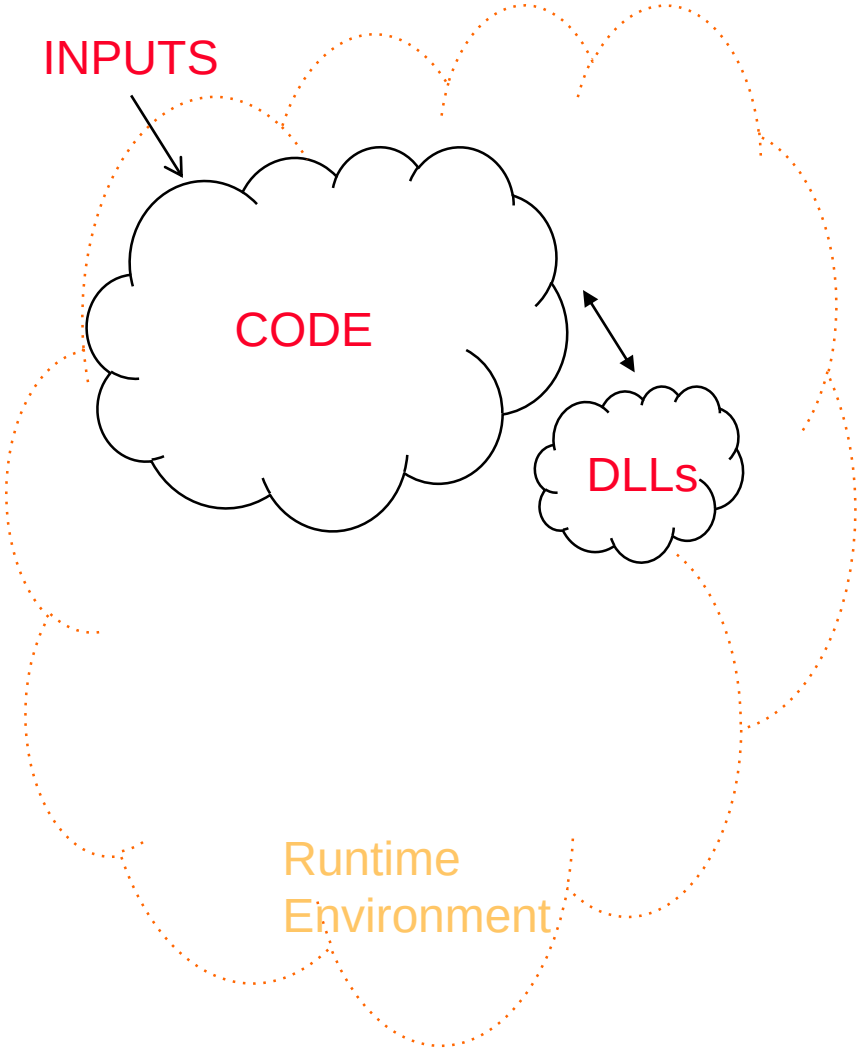
ACK= Jack Sampson

Hierarchy of structures within a program

- Static



- Dynamic



Hierarchy of structures within a program

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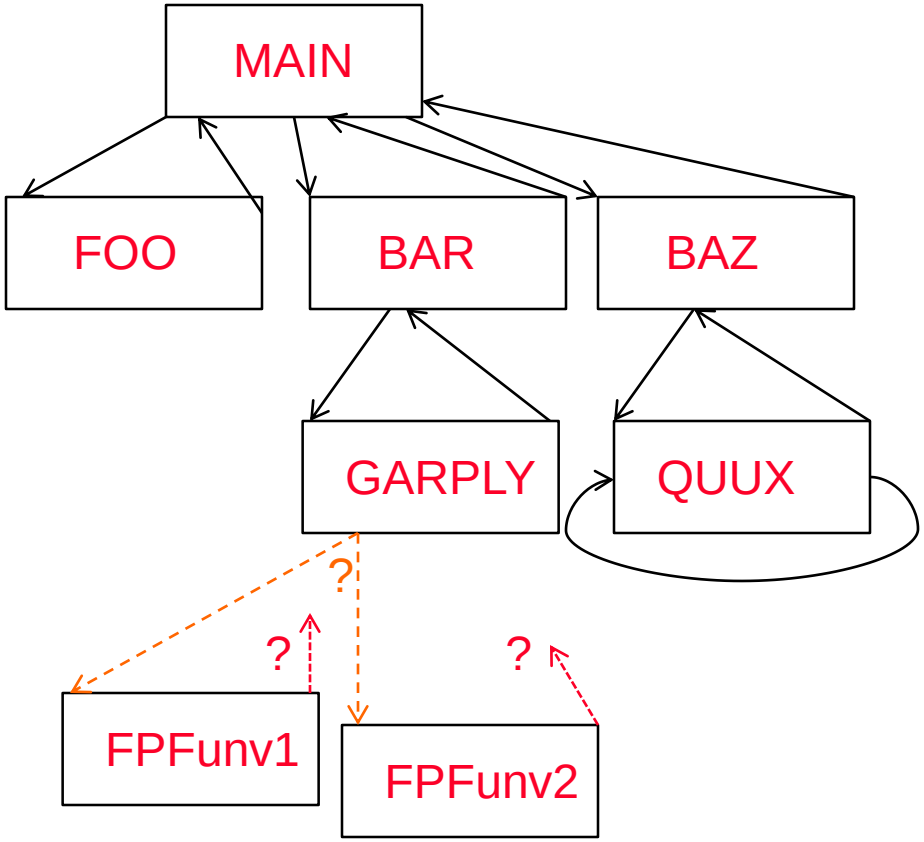
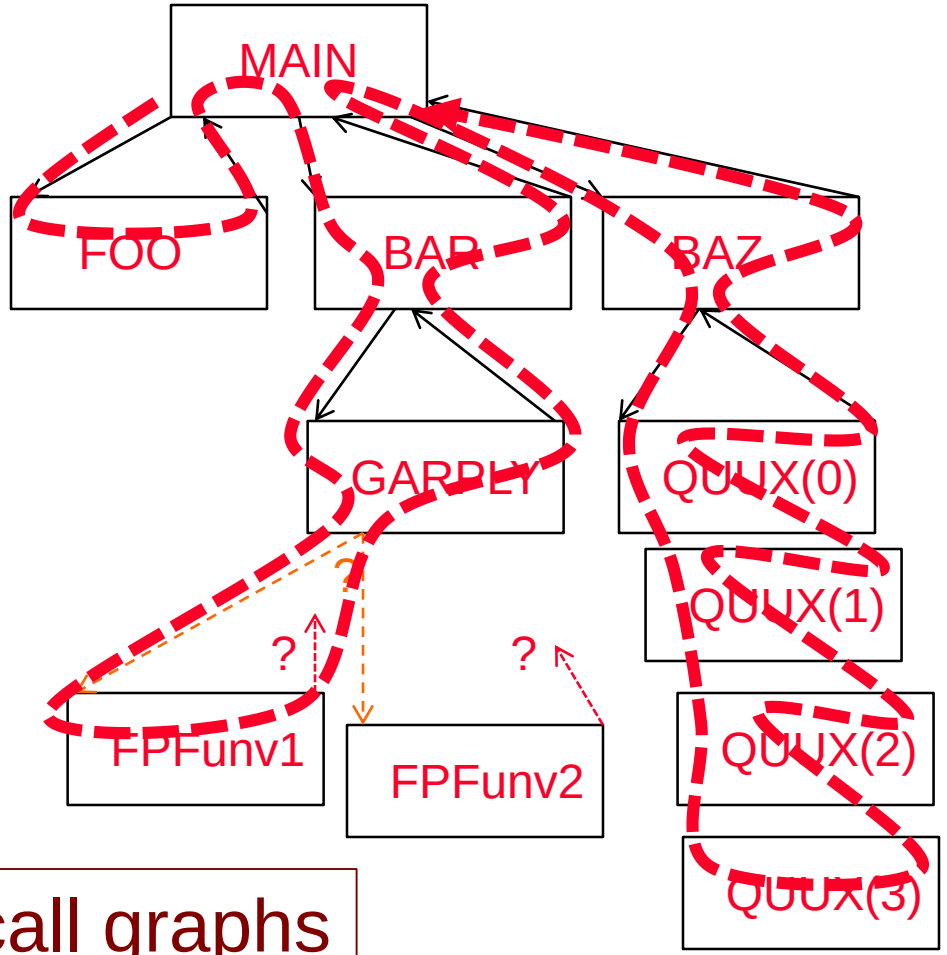


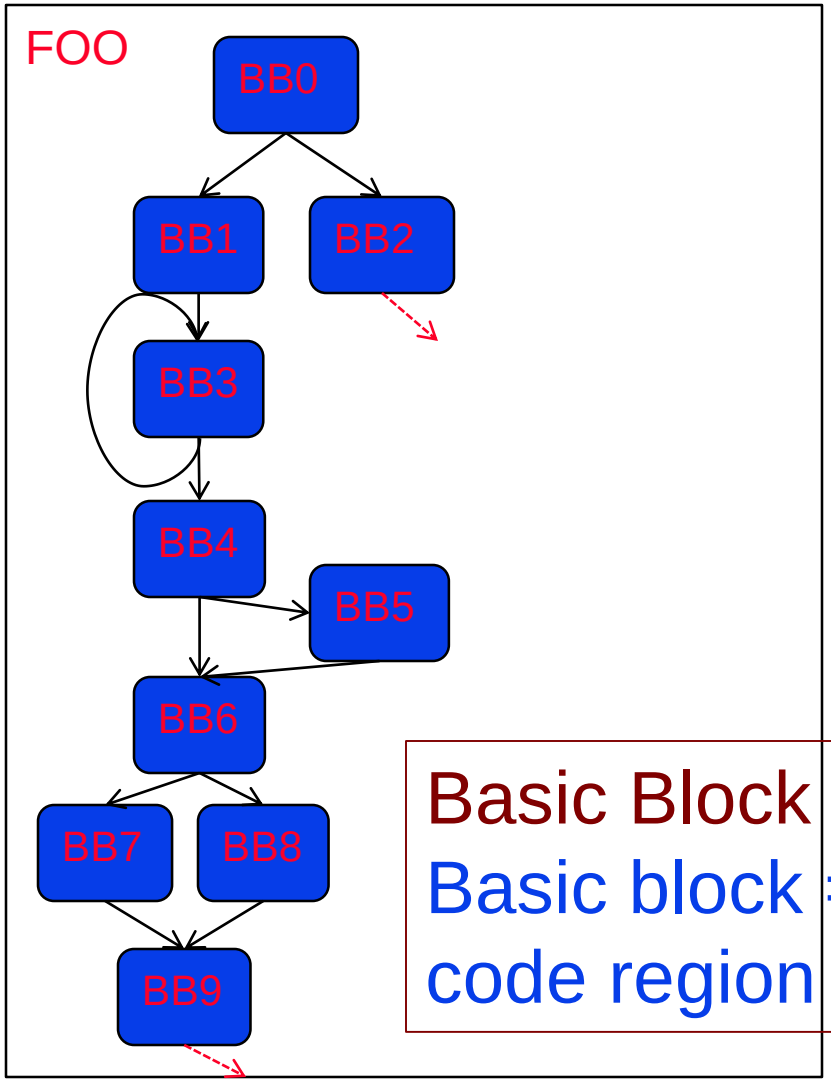
- Dynamic



Function call graphs

Hierarchy of structures within a program

- Static



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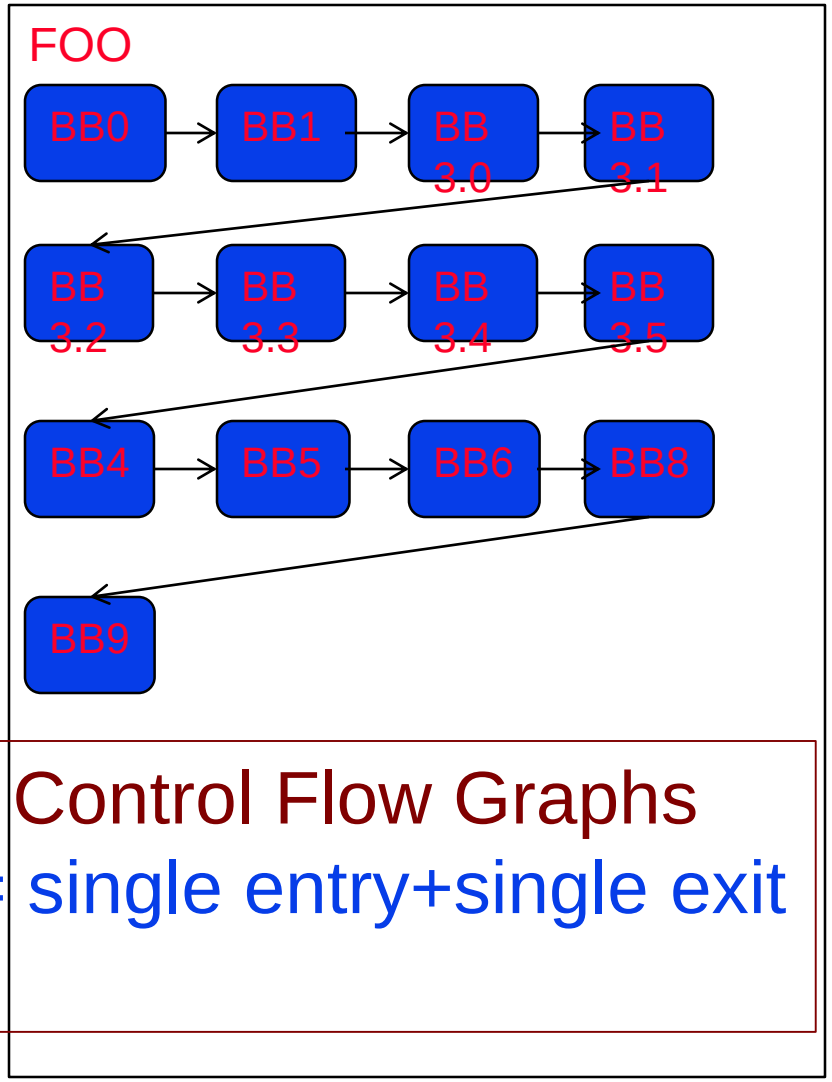


Basic Block = Basic block = code region

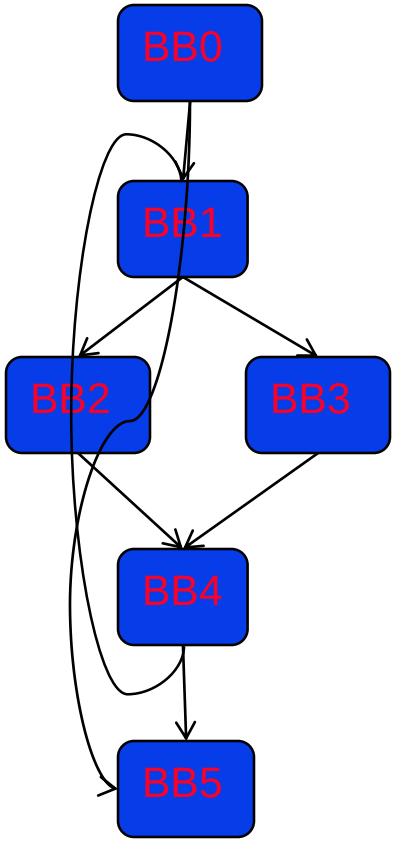
Control Flow Graphs = single entry+single exit

From Code to Structure

- Code

```
for (i=0;i<4;++i){
        if(a[i]<b[i])
                ++c1;
        else
                ++c2;
        c3+=a[i];
}
c4=c3+c1-c2;
```

- Control Flow Graph



From Code to Structure

- Code

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for (i=0;i<4;++i){
        if(a[i]<b[i])
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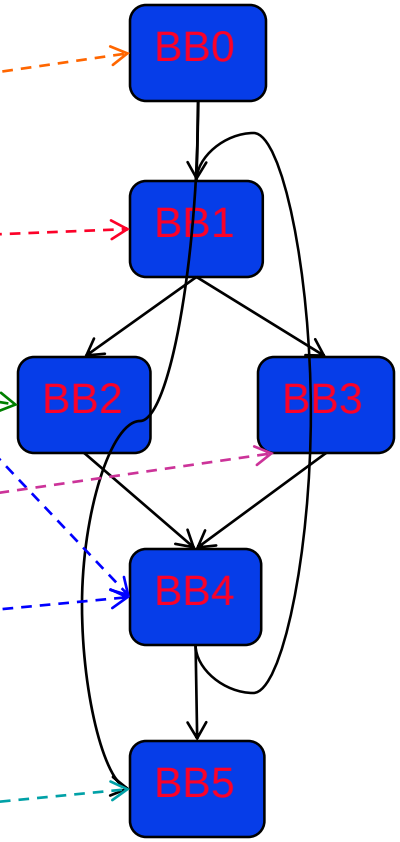
- Control Flow Graph



From Code to Structure

- Code

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for (i=0;i<4;++i){
        if(a[i]<b[i])
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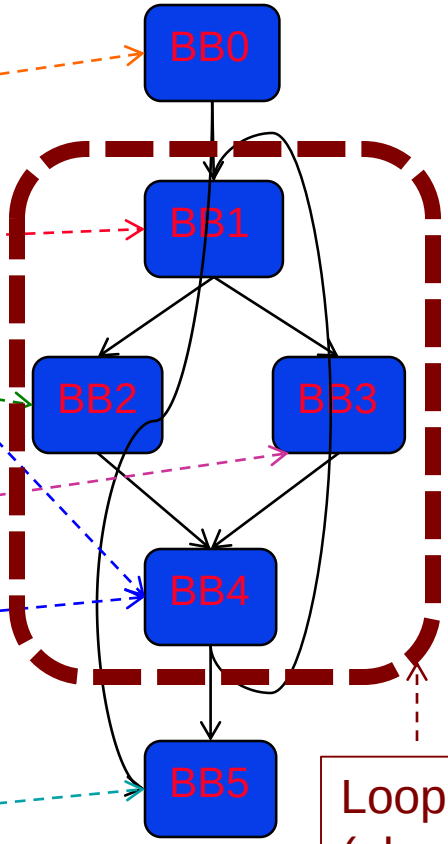
}
c4=c3+c1-c2;
```

- Control Flow Graph



Loop body
(also happens to be a “hyperblock”: a single entry multiple exit forward flow set of BBs)

From Code to Structure

- Code

```
for (i=0;i<4;++i){
        if(a[i]<b[i])
                ++c1;
        else
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        c3+=a[i];
}
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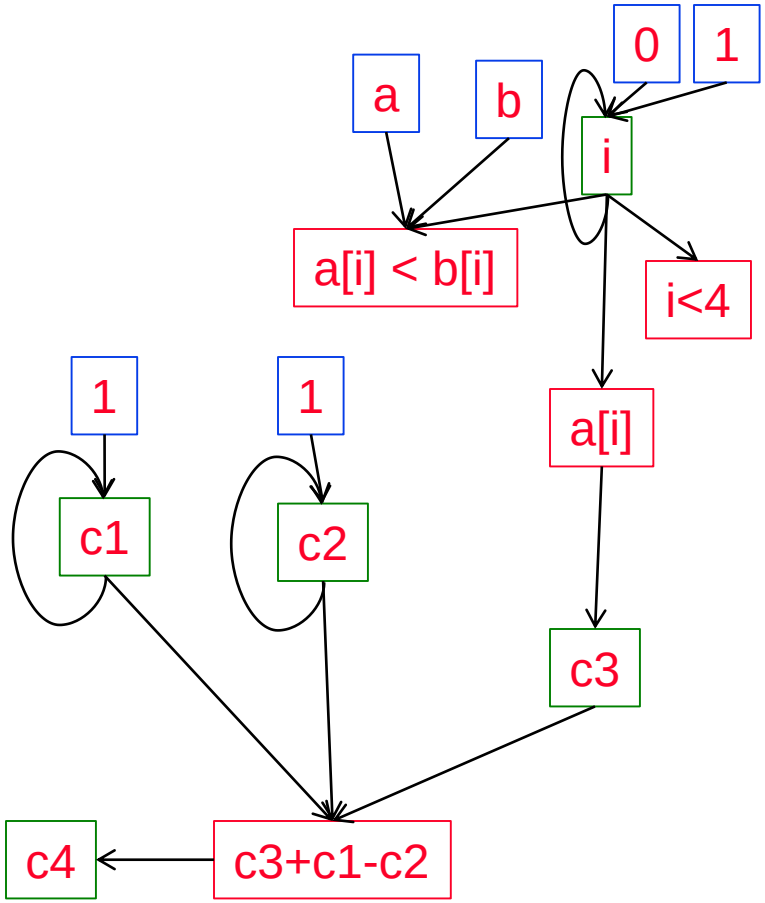
```

- Data Dependence Graph



From Code to Structure

- Code

```
for (i=0;i<4;++i){
        if(a[i]<b[i])
                ++c1;
        else
                ++c2;
        c3+=a[i];
}
c4=c3+c1-c2;
```

- Program Dependence

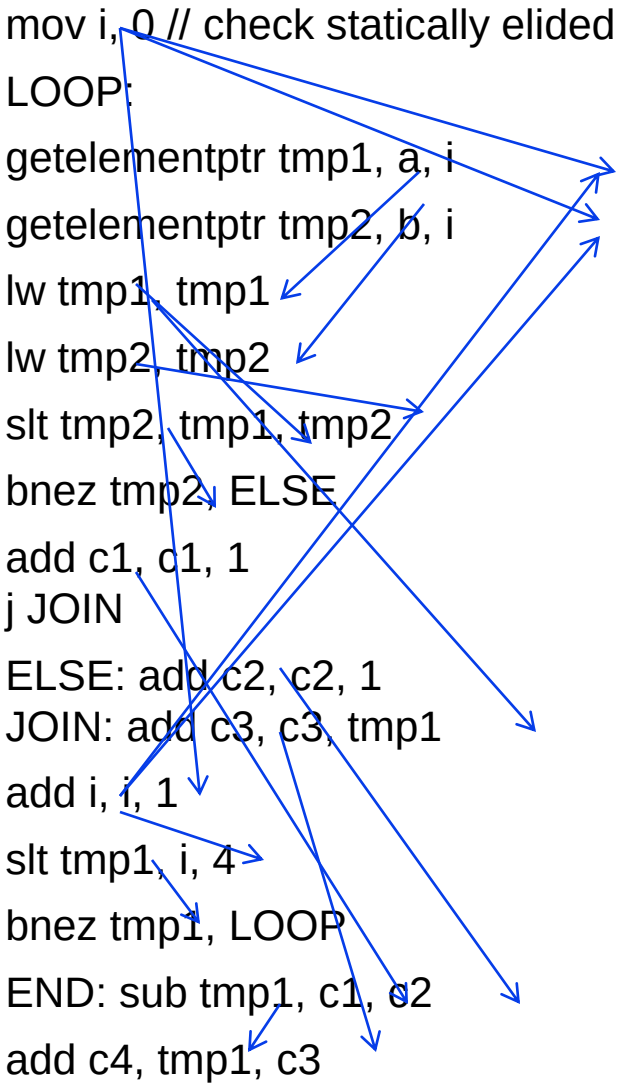
```
mov i, 0 // check statically elided
LOOP:
getelementptr tmp1, a, i
getelementptr tmp2, b, i
lw tmp1, tmp1
lw tmp2, tmp2
slt tmp2, tmp1, tmp2
bnez tmp2, ELSE
add c1, c1, 1
j JOIN
ELSE: add c2, c2, 1
JOIN: add c3, c3, tmp1
add i, i, 1
slt tmp1, i, 4
bnez tmp1, LOOP
END: sub tmp1, c1, c2
add c4, tmp1, c3
```

From Code to Structure

- Code

```
for (i=0;i<4;++i){
        if(a[i]<b[i])
                ++c1;
        else
                ++c2;
        c3+=a[i];
}
c4=c3+c1-c2;
```

- Program Dependence



From Code to Structure

- Code

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for (i=0;i<4;++i){
        if(a[i]<b[i])
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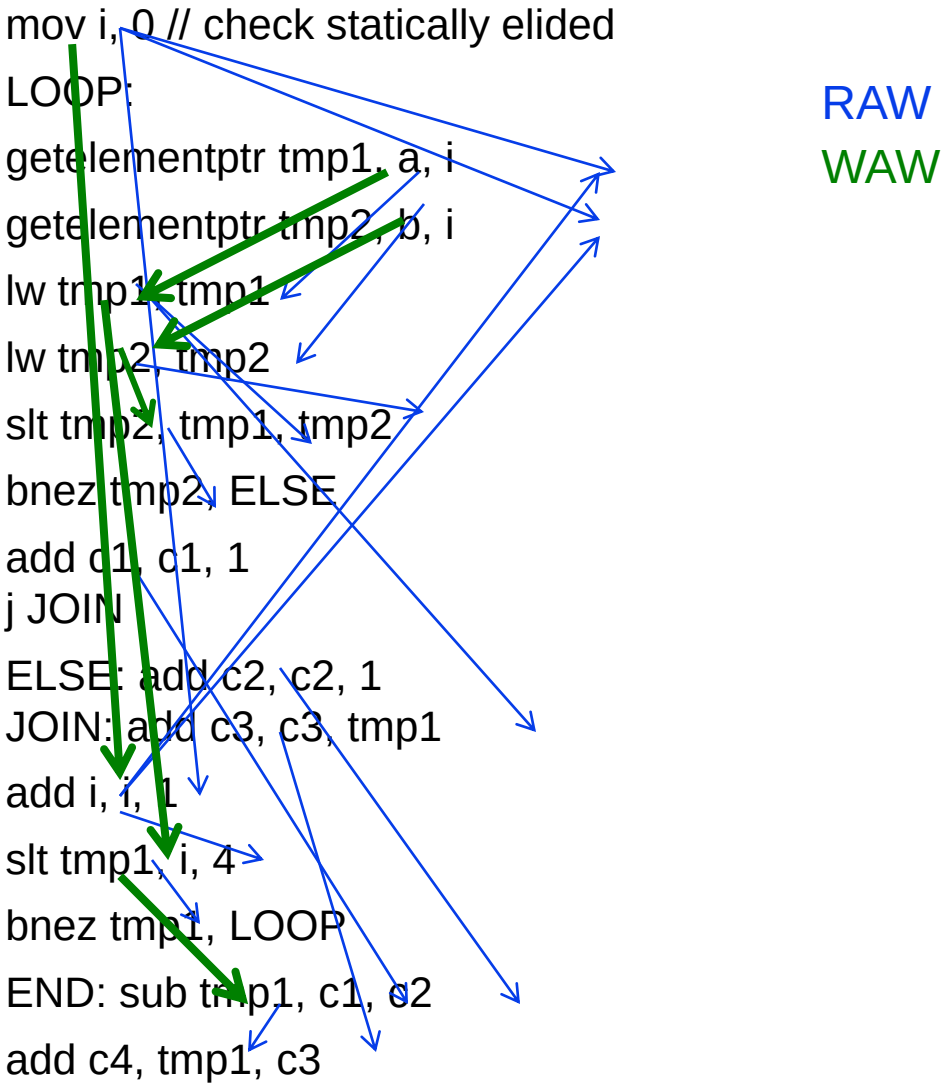
- Program Dependence



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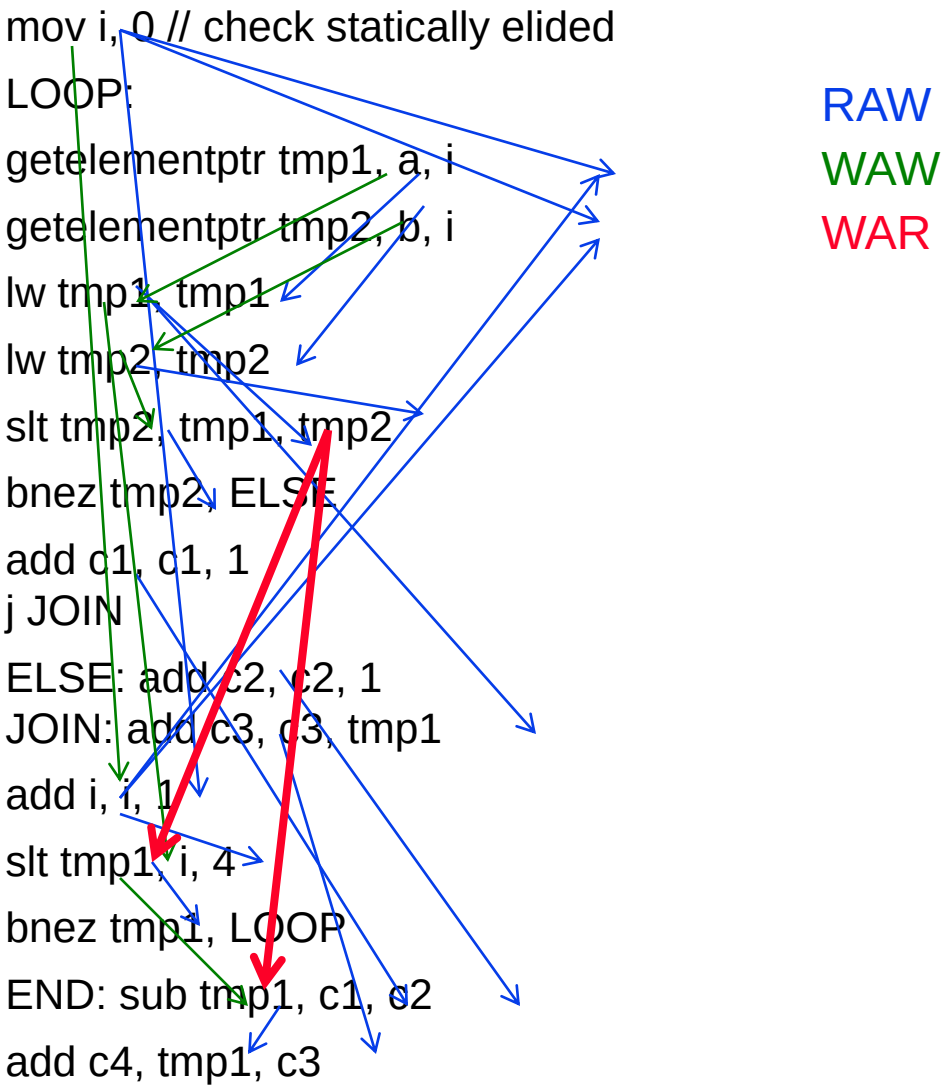
- Program Dependence



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        else
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        c3+=a[i];
}
c4=c3+c1-c2;
```

- Program Dependence

```
mov i, 0 // check statically elided
LOOP: phi i1, i, i1, BB0, BB4
getelementptr tmp1, a, i1
getelementptr tmp2, b, i1
lw tmp3, tmp1
lw tmp4, tmp2
slt tmp5, tmp3, tmp4
bnez tmp5, ELSE
add c1, c1, 1
j JOIN
ELSE: add c2, c2, 1
JOIN: add c3, c3, tmp3
add i1, i1, 1
slt tmp6, i1, 4
bnez tmp6, LOOP
END: sub tmp7, c1, c2
add c4, tmp7, c3
```

From Code to Structure

- Code

```
for (i=0;i<4;++i){
        if(a[i]<b[i])
                ++c1;
        else
                ++c2;
        c3+=a[i];
}
c4=c3+c1-c2;
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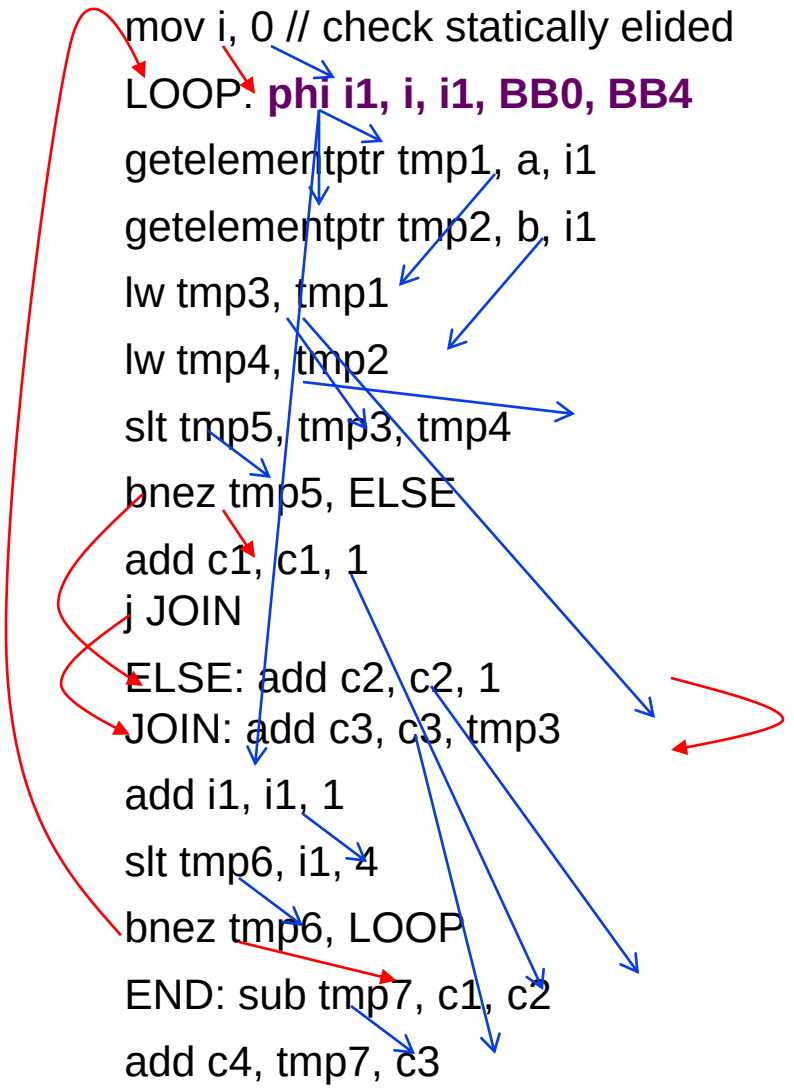
- Program Dependence



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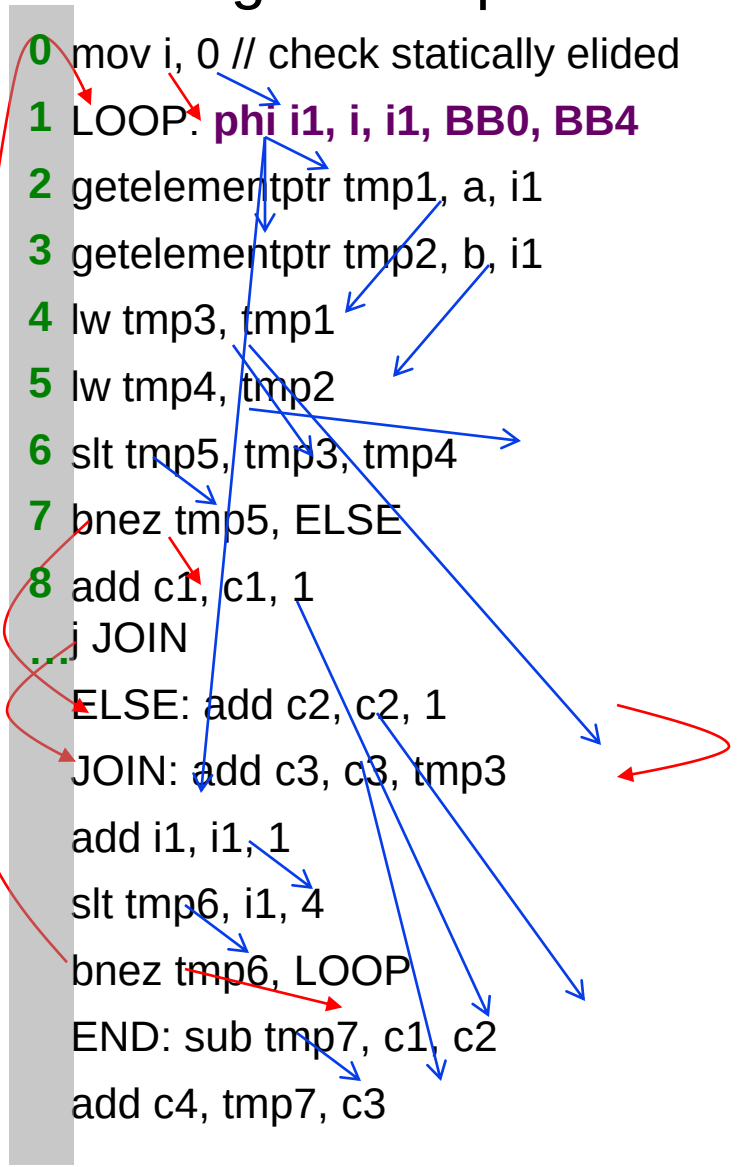
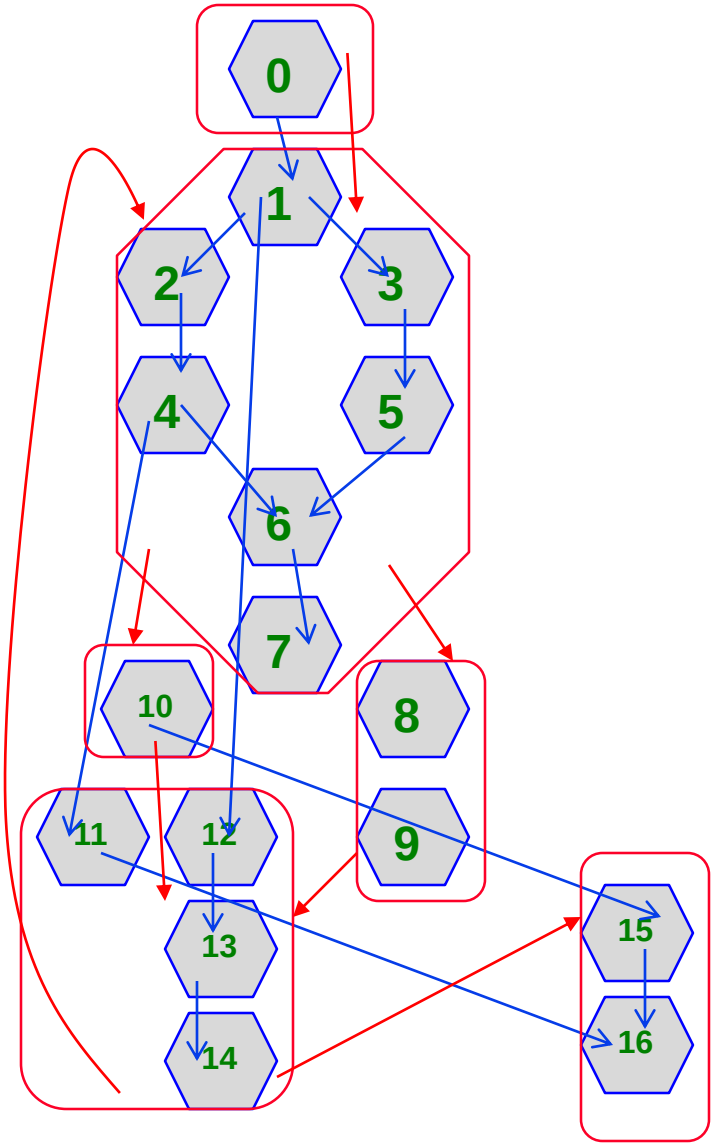


From Code to Structure

- Program Dependence Graph



- Program Dependence

```
0  mov i, 0 // check statically elided
1  LOOP: phi i1, i, i1, BB0, BB4
2  getelementptr tmp1, a, i1
3  getelementptr tmp2, b, i1
4  lw tmp3, tmp1
5  lw tmp4, tmp2
6  slt tmp5, tmp3, tmp4
7  bnez tmp5, ELSE
8  add c1, c1, 1
9  j JOIN
10 ELSE: add c2, c2, 1
11 JOIN: add c3, c3, tmp3
12 add i1, i1, 1
13 slt tmp6, i1, 4
14 bnez tmp6, LOOP
15 END: sub tmp7, c1, c2
16 add c4, tmp7, c3
```

So What?

- View seen by compiler
  - Helps understand what optimizations are/are not possible and when
  - Helps understand what information is lost during code generation
- Limitations of PDGs are targets for optimizations
  - Control dependence → branch prediction, dynamic unrolling, predication
  - WAR/WAW → hardware renaming
  - Memory dependence ambiguity → speculative loads
  - RAW → Scheduling, latency hiding, value prediction
  - Limited Von Neumann parallelism / parallelism information → dynamic scheduling, dynamic unrolling, dynamic PDG reconstruction
- Important to understand static vs. dynamic view of execution
  - Possible relationships / always relationships vs. this time relationships
  - Different analysis / optimizations possible