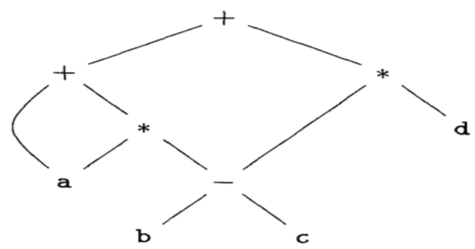
Optimization of Basic blocks

- It is a linear piece of code.
- Analyzing and optimizing is easier.
- Has local scope - and hence effect is limited.
- Substantial enough, not to ignore it.
- Can be seen as part of a larger (global) optimization problem.

DAG representation of basic blocks

Recall: DAG representation of expressions

- leaves corresponding to atomic operands, and interior nodes corresponding to operators.
- A node N has multiple parents - N is a common subexpression.
- Example: `(a + a * (b - c)) + ((b - c) * d)`



DAG construction for a basic block

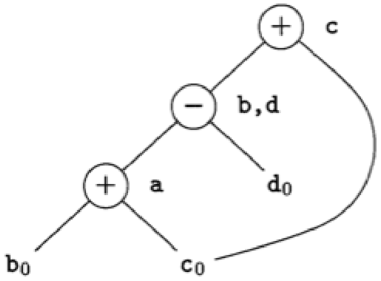
- There is a node in the DAG for each of the initial values of the variables appearing in the basic block.
- There is a node N associated with each statement s within the block. The children of N are those nodes corresponding to statements that are the last definitions, prior to s, of the operands used by s.
- Node N is labeled by the operator applied at s, and also attached to N is the list of variables for which it is the last definition within the block.
- Certain nodes are designated output nodes. These are the nodes whose variables are live on exit from the block;

Optimizations on the DAG

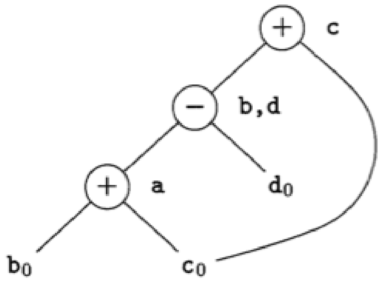
- Common subexpression elimination.
- Eliminate dead code.
- Code reordering.
- Algebraic optimizations.

Construct the DAG. Example

```
a = b + c
b = a - d
c = b + c
d = a - d
```



Example (contd)



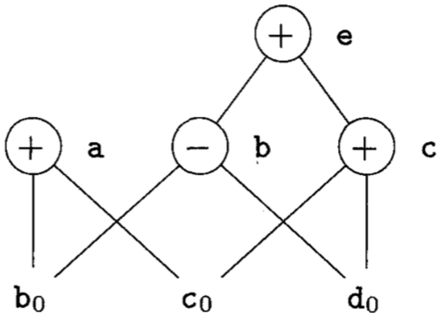

```
a = b + c
d = a - d
c = d + c

// if  b is live
b = d
```

Q: How to know if `b` is live after the basic block?

Limitations of the DAG based CSE

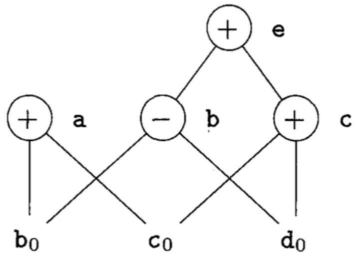
```
a = b + c
b = b - d
c = c + d
e = b + c
```



- The two occurrences of the sub-expressions `b + c` computes the same value.
- Value computed by `a` and `e` are the same.
- How to handle the <u>algebraic identities</u>?
- Q: Do the sub-expressions <u>always</u> compute the same value?

Dead code elimination

- Delete any root from DAG that has no ancestors and is not live out (has no live out variable associated).
- Repeat previous step till no change.



- Assume `a` and `b` are live out.
- Remove first `e` and then `c`.
- `a` and `b` remain.

CSE via Algebraic identities

- Recall: In common sub-expression elimination, we want to reuse nodes that compute the same value.
- Recall: We mainly focussed on syntactic similarities.
- Q: Can we go beyond that?

Similarities in the semantics - identity, inverse, zero

```
x + 0 = 0 + x = x

x * 1 = 1 * x = x    identity, examples?

a && true = true && a = a

a || false = false || a = a

x * 0 = 0 * x = 0

0 / x = 0
```

Goal: apply arithmetic identities to eliminate computation.

Similarities in the semantics - strength

```
x^2 = x * x

2 * x = x + x = x << 1 (?)

x/2 = x * 0.5 = x >> 1 (?)

Constant folding

2 * 0.123456789101112131415 = 0.246913578202224262830
```

Chapernowne's constant

Goal: identify equivalence module strength reduction operations.

Algebraic properties

- Commutative: Say the operator * is commutative. x * y = y * x
- Associative: a + (b - c) = (a + b) - c

  ```
  a = b + c
  e = c + d + b
  ->
  a = b + c
  t = c + d
  a = t + b
  -> (assuming t is not used anywhere else)
  a = b + c
  e = a + d
  ```
- `a = b - 1; c = a + 1 → c = b`

How to?

In general the problem is that of checking equivalence of two expressions – Undecidable!

A rough idea:

- When creating the DAG, create the node for expression that has the most reduced strength.
- For each expression e,
  - Take all "sub-expressions" that "build" the operands of e.
  - Build a new large expression using these sub-expressions.
  - Simplify the large expression.
  - Check if the simplified expression (or part thereof) or any variations thereof can be found in the tree.
  - Build sub-tree for the rest.

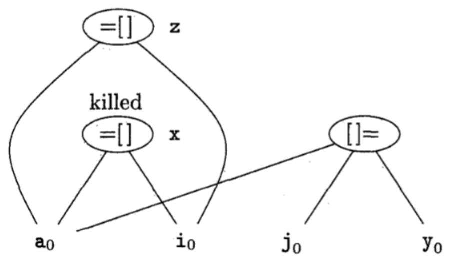
Restrictions

- The language manual may restrict.
  - Fortran: you can evaluate any equivalent expression, but cannot violate the integrity of paranthesis.
  - Thus `x * y - x * z` $\rightarrow$ `x * (y - z)`
  - But `a + (b - c)` $\neq$ `(a + b) - c`
- Keep a language manual handy if you are writing a compiler!

Representing Array accesses in the DAG

```
x = a[i]
a[j] = y
z = a[i]
```

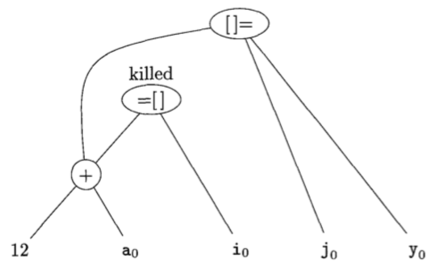
Q: Is a[i] a common sub-expression?



Array representation (2)

```
b = a + 12
x = b[i]
b[j] = y
```

Q: Say, elements of 'a' are 4bytes size



Home reading: How to handle pointers.

Peephole optimization

- A local optimization technique.
- Simplistic in nature, but effective in practise.
- Idea:
  - Keep a sliding window (called peephole)
  - Replace instruction sequences within the peephole by a by an efficient (shorter / faster / ...) sequence.

Peephole optimization

- The “peephole” is typically small. Why?
- The code in the peephole need not be contiguous.
- Each improvement may lead to additional improvements.
- In general, we may have to make multiple passes.

Eliminating redundant loads and stores

```
Load a, R0
Store R0, a
```

Delete the pair of instructions. Always?

What if there is a label on the store instruction?

We need to be sure that the `Store` instruction and `Load` are executed as a pair.

Why would we have such stupid code?

Eliminating unreachable code

- An unlabelled statement after an unconditional jump – can be removed.
```
goto L2
INCR R0
L2:
```
- Eliminating jumps over jumps:
```
    if class == 2010 goto L1
    goto L2
L1: print 22
L2:
```
$\rightarrow$
```
if class != 2010 goto L2
print 22
L2:
```
- What can constant propagation do?

Flow-of-control optimizations

- Naive code generation creates many jumps.
- Jumps to jumps can be short circuited!

```
goto L1
...
L1: goto L2
```

Can be replaced with

```
goto L2
...
L1: goto L2
```

Further optimizations on `L1` are possible.

Similar situation with conditional jumps

```
if (cond) goto L1
...
L1: goto L2
```


Algebraic simplification and strength reduction

- Eliminate identity operations.
- Replace x^2 by $x * x$, and so on.
- Replace fixed-point mult by a power of two (by left-shift) and divison by a power of two (by right shift).
- Replace floating-point divison by multiplication!

Machine specific peephole optimization

- Use auto-incremenet / auto-decrement if available.
  add r1, (r2)+ $\rightarrow$ r1 = r1 + M[r2]; r2 = r2+d
- A cool PA-RISC instruction called `sh2add`
  r2 = r1 * 5 $\rightarrow$ sh2add r1, r1, r2
- PA-RISC instruction `ADDBT, <= r2, r1, L1`

Peephole procedure

- First make a list of patterns that you want to replace with a list of target patterns.
- Identify the pattern in the code and do the replacement.
- Iterate till you are done.
- Can be efficiently done on an DAG.
- No guarantees about optimality.
- Most of the peephole optimizations guarantee improvement.