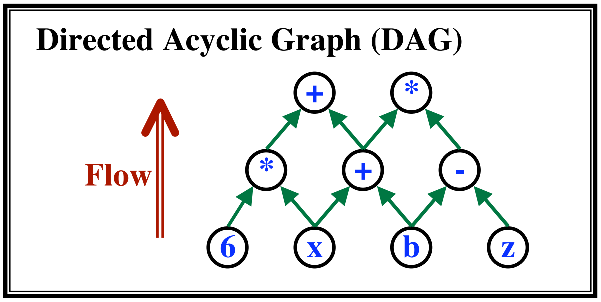
DAG-Based Optimization

of IR Code in a Basic Block



Look at one Basic Block at a time

```
<x,v,w> := f(x,b,z)
```

Construct a DAG from the IR.

Generate code from the DAG.

- Generate IR Code
- Generate Target Code

Leaves

Represent initial values on entry to the block

- Variables
- Constants

Interior Nodes

Labelled by operators

Also:

Each interior node may have an attached list of variable names

Example

Source Code:

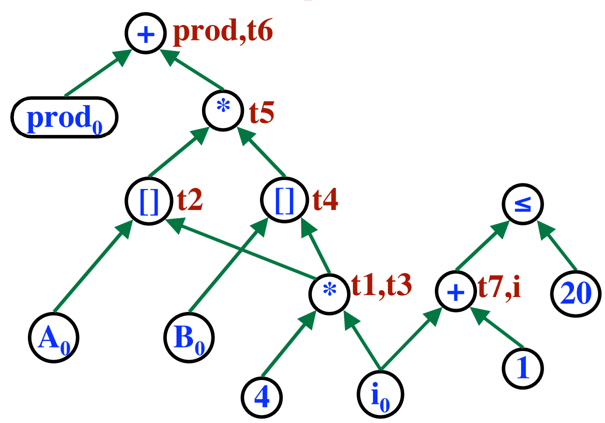
```
repeat
  prod := prod + A[i] * B[i];
  i := i + 1;
until i > 20;
```

Assume each array element is 4 bytes

IR:

```
t1  := 4 * i
t2  := A[t1]
t3  := 4 * i
t4  := B[t4]
t5  := t2 * t4
t6  := prod + t5
prod := t6
t7  := i + 1
i  := t7
if i <= 20 goto BB9
```

- Go through IR instructions.
- For each operation construct a new node.
- Label each node.
- Re-use existing nodes, when possible.



Mappings

Functions:

- Domain
- Range

Supply an element from the domain...

The function returns an element from the range.

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A data structure that implements a function.
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A mapping from Strings to Integers. (e.g., a phone book)
A mapping from Variables to VarDecls (e.g., a symbol table)

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Examples:

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A mapping from Variables to VarDecls (e.g., a symbol table)

Basic Operations:

Lookup (key) → value
AddEntry (key, value)
DeleteEntry (key)
...etc...

Visual Representations

key	value
"Porter"	725-4039
"Brown"	725-1234
"Tolmach"	725-3434
"Fant"	725-7654
"Antoy"	725-4050
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Visual Representations

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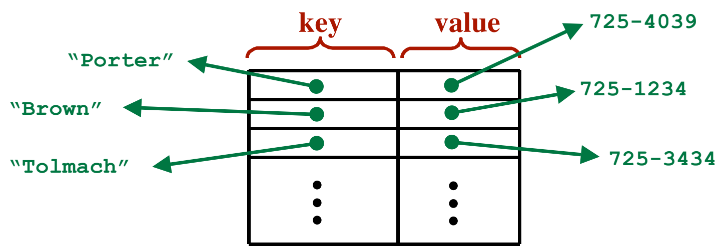

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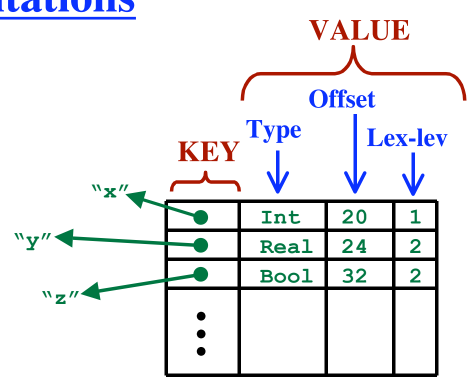

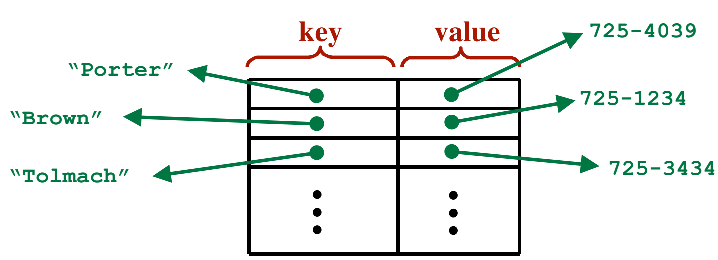

Implementation

A Mapping from small Integers to ...

Use an Array

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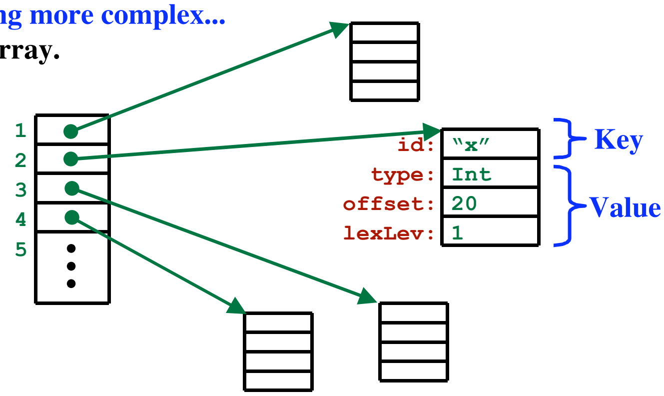
Use an Array

If the key is something more complex...

Can still use an array.



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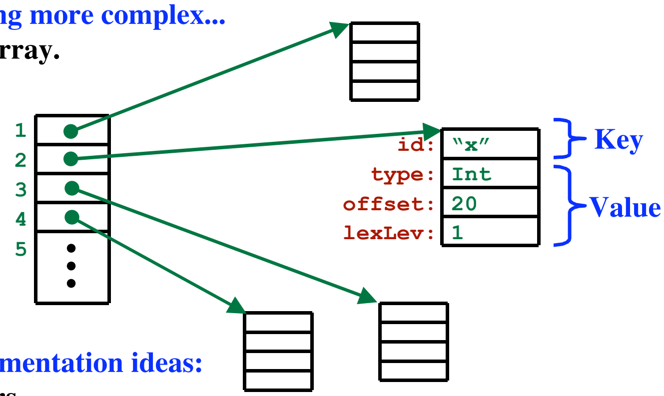


More complex implementation ideas:

- Objects, Pointers
- Linked Lists
- Arrays
- Binary Trees
- Hash Tables

Basic Operations:

Lookup (key) → value
AddEntry (key, value)
DeleteEntry (key)
...etc...

Building the DAG

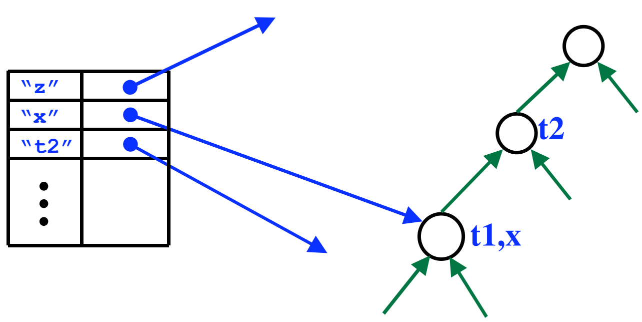
Need a mapping

Call it "CurrentNode"

FROM: Variable Names

TO: Nodes in the DAG

CurrentNode (x) points to the node currently labelled with "x".



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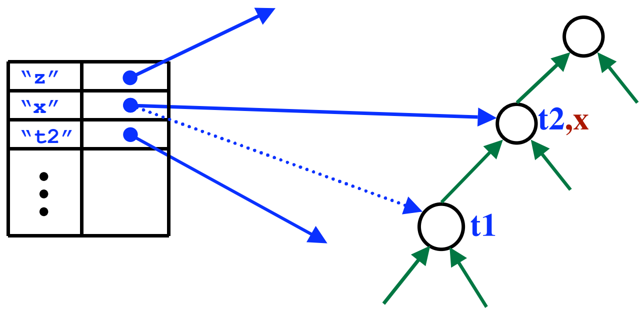


Algorithm to Construct the DAG

Go through the Basic Block (in order)
For each IR in the block...

Add to the growing DAG...
Assume we have a binary IR instruction, such as

x := y $\oplus$ z

If CurrentNode(y) is undefined...
Create a leaf named "y_0".
Set CurrentNode(y) to point to it.
If CurrentNode(z) is undefined...
<same>
Look for a node labelled "$\oplus$"
with left child = CurrentNode(y)
and right child = CurrentNode(z)
(If none found, then create one.)
Call this node N.
Delete x from the list of ID's attached
to CurrentNode(x).
Add x to the list of ID's attached to N.
Set CurrentNode(x) to point to N.

Algorithm to Construct the DAG

If we have a unary operation, such as

```
    x := -y

If CurrentNode(y) is undefined...
    Create a leaf named "y0".
    Set CurrentNode(y) to point to it.
Look for a node labelled "-"
    with child = CurrentNode(y)
         (If none found, then create one.)
Call this node N.
Delete x from the list of ID's attached
            to CurrentNode(x).
Add x to the list of ID's attached to N.
Set CurrentNode(x) to point to N.
```


Algorithm to Construct the DAG

If we have a copy operation

```
    x := y

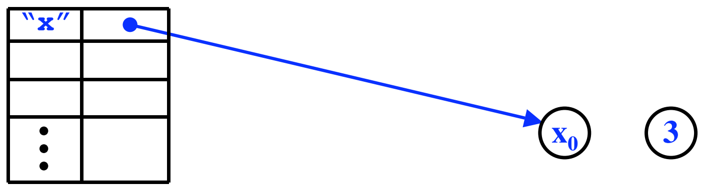
If CurrentNode(y) is undefined...
    Create a leaf named "y0".
    Set CurrentNode(y) to point to it.
Let N = CurrentNode(y)
Delete x from the list of ID's attached
            to CurrentNode(x).
Add x to the list of ID's attached to N.
Set CurrentNode(x) to point to N.
```

Example

IR Code:

```
x := x * 3
y := y + x
x := y - z
y := x
```

IR Code:



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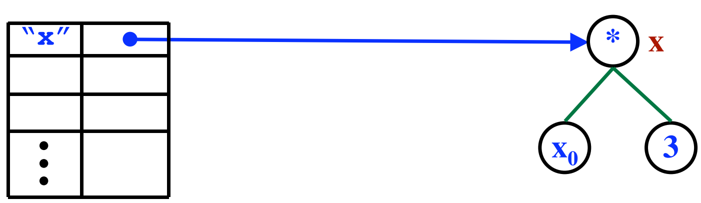

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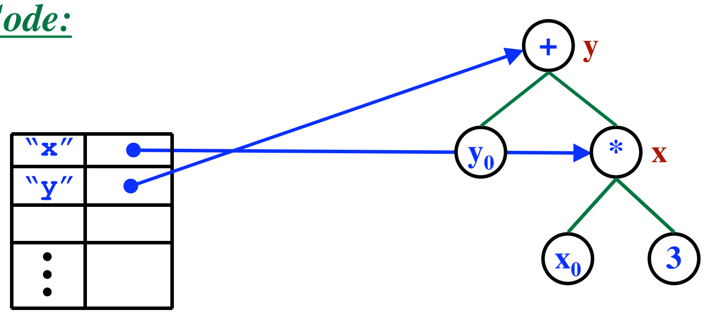

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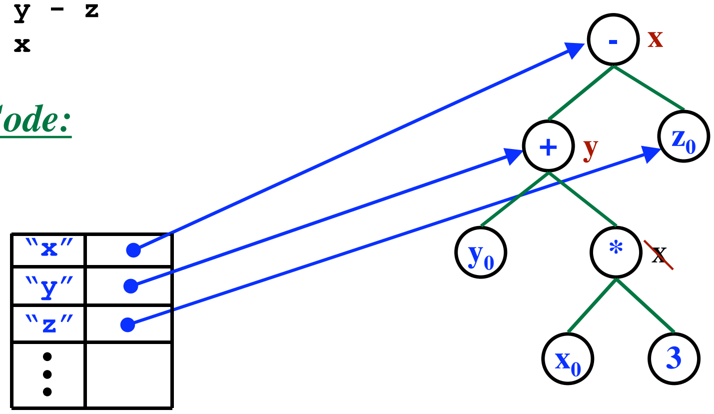

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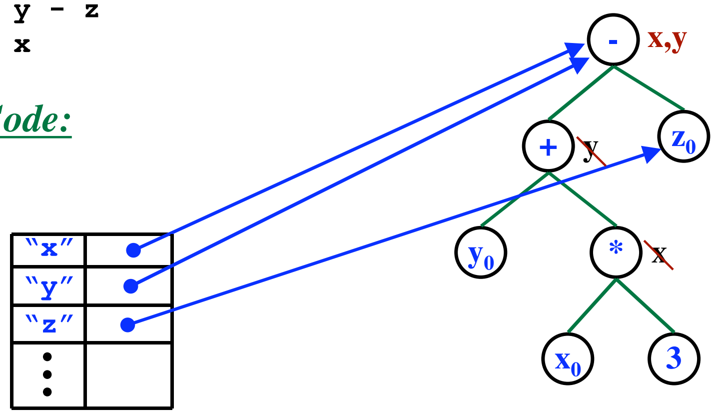
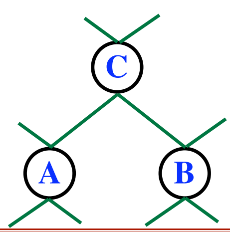


Topological Sort

An ordering of the nodes of the DAG.
Each node must be listed after all its children.



...B...A...C...

Idea:

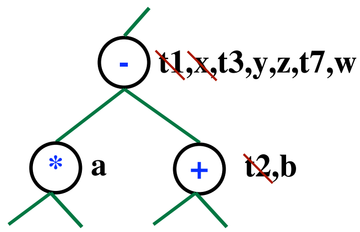
Find a topological order of nodes.
Evaluate a node after all its children have been evaluated.
...and before it is needed by its parents!

Summary:

- Build DAG
- Find topological order
- Regenerate IR instructions.

To Regenerate the IR Code

Look at each node, in topological order...

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a := ...
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Some of the labels have been removed from the list.

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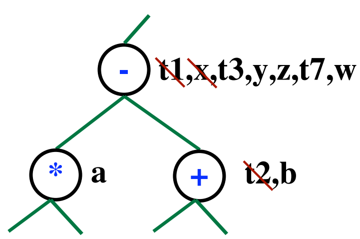


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a := ...
b := ...
```

Some of the labels have been removed from the list.

Of the remaining labels
see which are LIVE at the end of the Basic Block.

Ignore the DEAD variables; select a live variable.
(If no LIVE variables, create a temp variable.)

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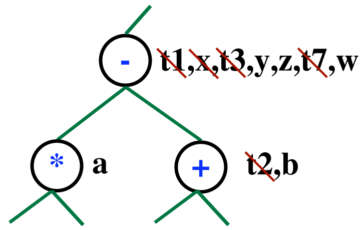


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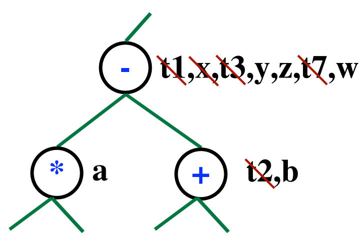


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y := a - b
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Generate an IR instruction for the operation.

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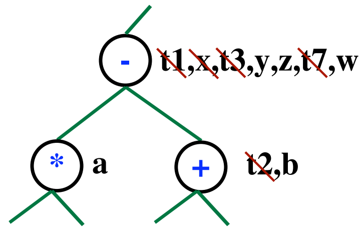


```
a := ...
b := ...
y := a - b
z := y
w := y
```

Some of the labels have been removed from the list.

Of the remaining labels
see which are LIVE at the end of the Basic Block.

Ignore the DEAD variables; select a live variable.
(If no LIVE variables, create a temp variable.)

Generate an IR instruction for the operation.

Generate copies for any additional LIVE variables.

Example

Before:

```
t1 := 4 * i
t2 := A[t1]
t3 := 4 * i
t4 := B[t4]
t5 := t2 * t4
t6 := prod + t5
prod := t6
t7 := i + 1
i := t7
if i <= 20 goto BB9
```

Now:

```
t1 := 4 * i
t2 := A[t1]
t4 := B[t1]
t5 := t2 * t4
prod := prod + t5
i := i + 1
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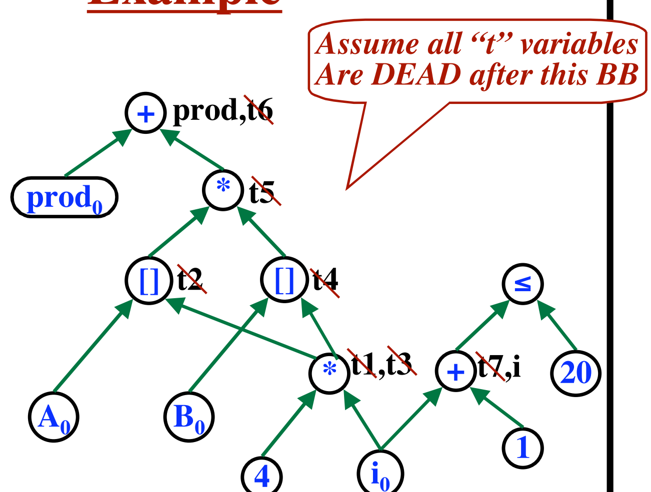
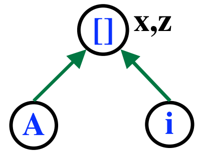


Problems

Assignments to Arrays

```
x := A[i]
A[j] := 43
z := A[i]
```



Will "x" and "z" be set to the same value? Possibly not!!!

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x := A[i]
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The Optimized Code:

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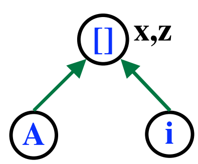
x := A[i]
z := x
A[j] := 43
```



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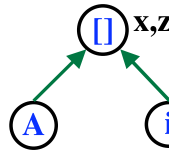
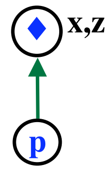


Will "x" and "z" be set to the same value? Possibly not!!!

Indirect Assignments (through pointers)

```
x := *p
*q := z
z := *p
```



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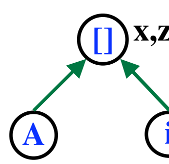

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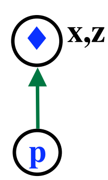
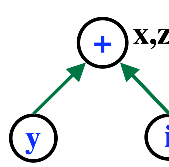


"Equivalenced" Names

```
x := y + i
w := 43
z := y + i
```



What of "w" is another Name for "y"???

Solution #1

Put things like

A[..] := ...

*p := ...

call ...

into their own blocks.

Solution #2

When building the DAG...

We try to re-use nodes

Look for a node labelled “+” with operands “x” and “y”...

If found, use that node.

Else, create a new node.

Array Accesses -- always do the fetch from the array

Pointer Indirection -- always do the fetch from memory

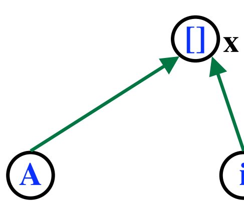
Also, we need to impose some order constraints.

Order Restrictions

```
x := A[i]

A[j] := y

z := A[i]
```



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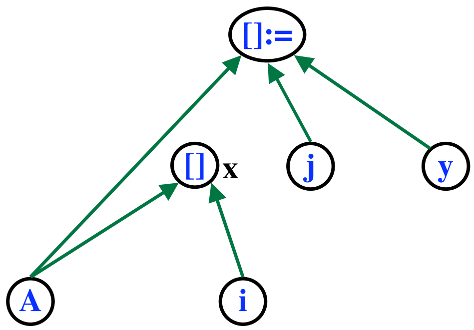

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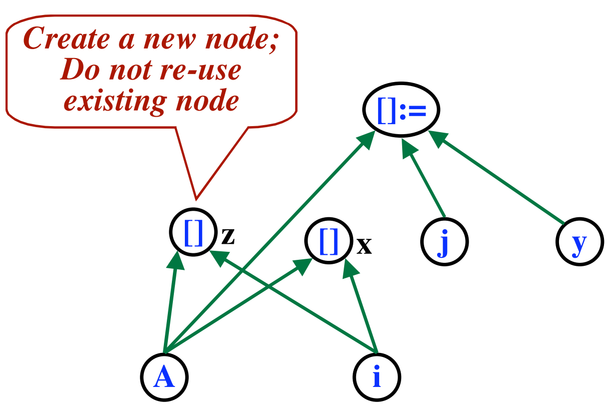

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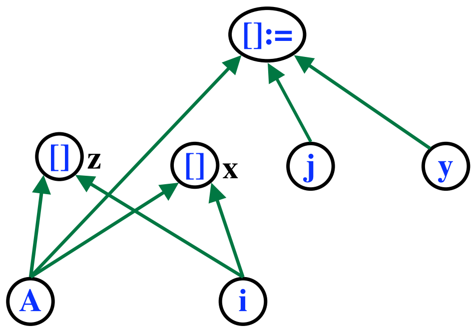

Order Restrictions

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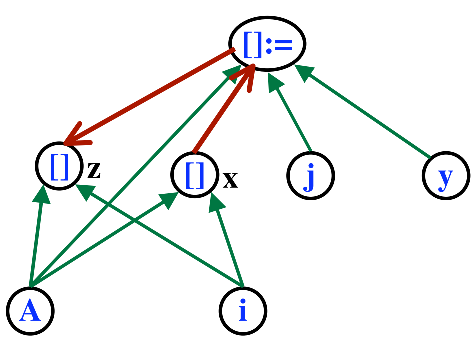
Must follow

Must follow

Add special edges the DAG to show the order restrictions.



Order Restrictions

```
…[…]  := ...
      ↓
...  := …[…]
```

```
*p := ...
      ↓
... x ...
```

```
call …
      ↓
... x ...
```

```
...  := …[…]
      ↓
…[…]  := ...
```

```
... x ...
      ↓
*p := ...
```

```
... x ...
      ↓
call …
```