Optimize Your Programs, Elegantly

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Agenda

- Introduction.
- Dijkstra's Shortest Paths.
- Topological Ordering.

You can make your programs more elegant by

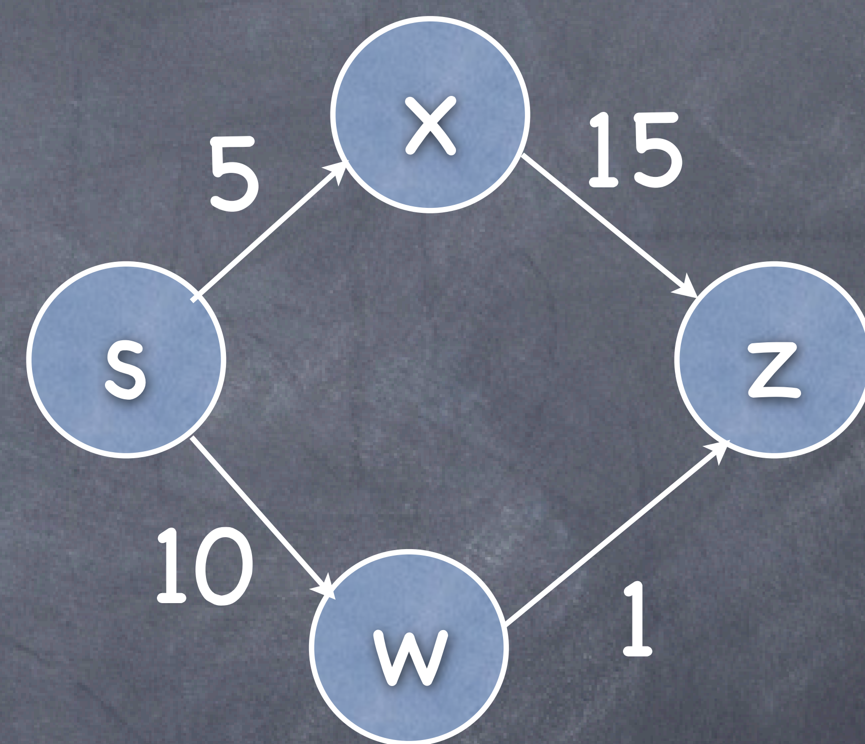
- Having "components that influence other components".
- BTW, these are called "aspects".
- AspectJ is a general purpose programming languages for developing aspects.
- You can also simulate **<u>some</u>** what AspectJ aspects do using inheritance:
  - A subclass is an influenced version of its superclass. (Java)
  - Mixins, Traits produce influenced versions of classes. (Scala)

Figuring Out Aspects

- We recommend that you figure out aspects right from the requirements rather than refactoring your program into aspects.
- Efficiency is one such requirement that can be implemented as an aspect.

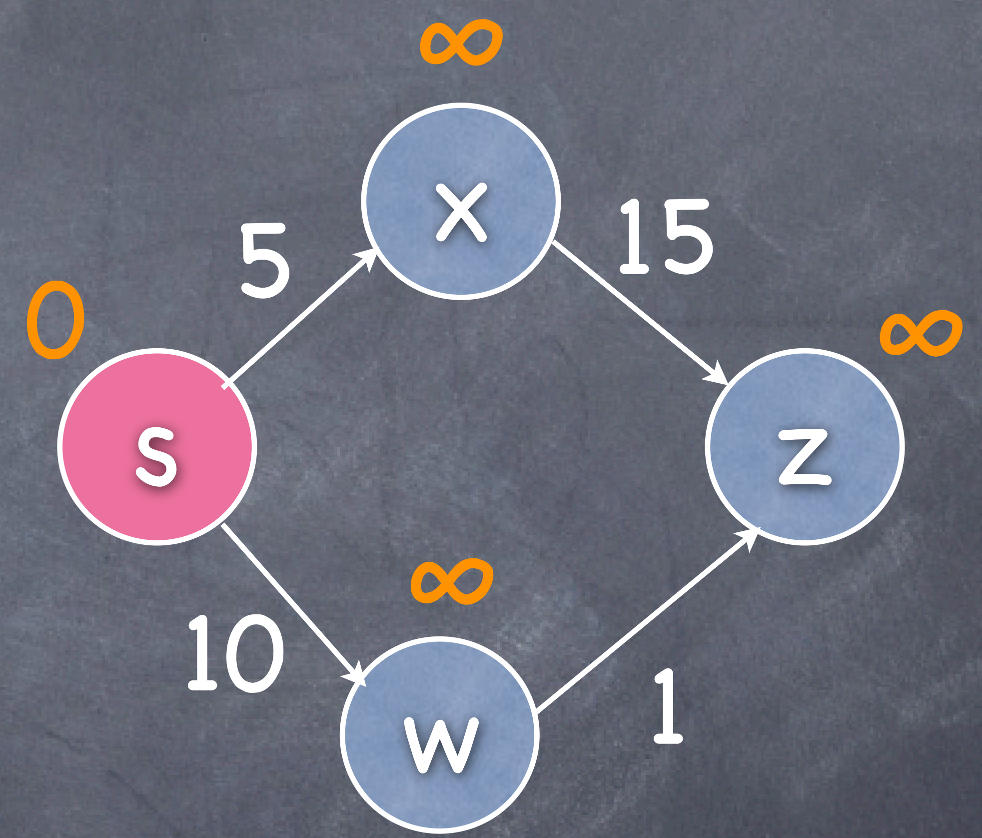
Dijkstra's Shortest Paths

- Given a weighted Graph (g) and a source node (s), find the shortest path from s to all nodes in g.



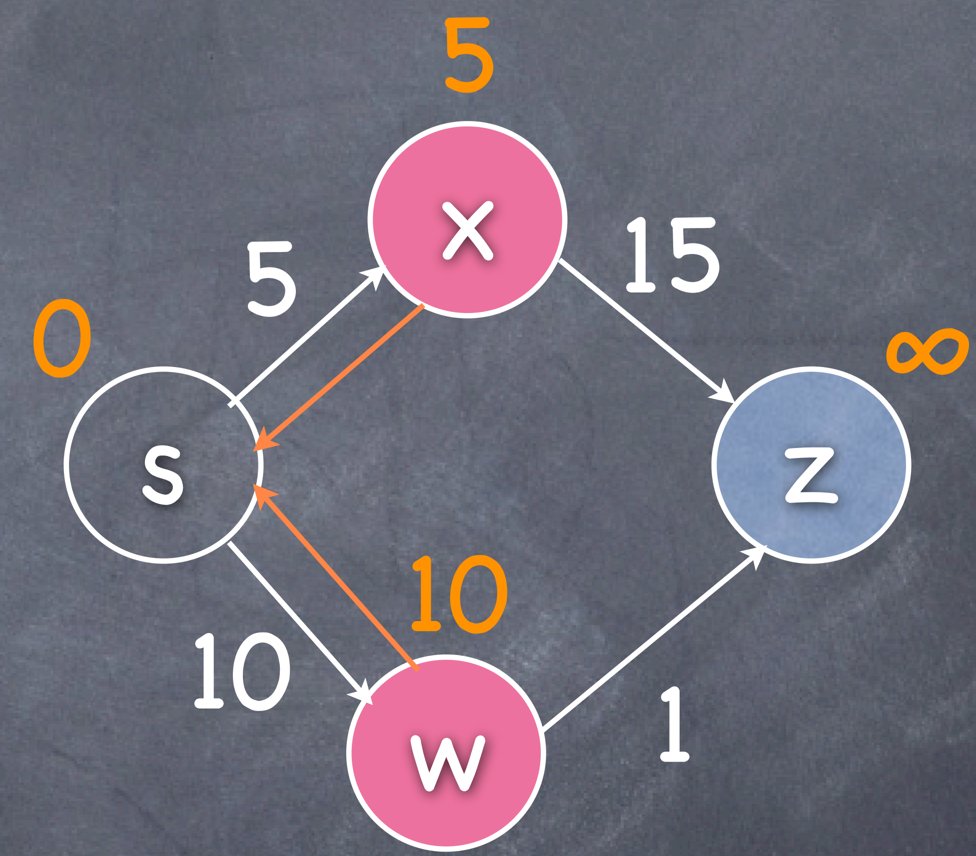
Dijkstra's Shortest Paths

- To each node, maintain it's best known distance from source and its predecessor on the shortest path from source.
- Maintain a list of active nodes. Initially = {S}.
- Maintain a list of final nodes. Initially = {}



Dijkstra's Shortest Paths

- Select the closest to source active node (v).
- Update the best known distance as well as predecessors of v's successors that are not marked as final.
- Mark v as final.



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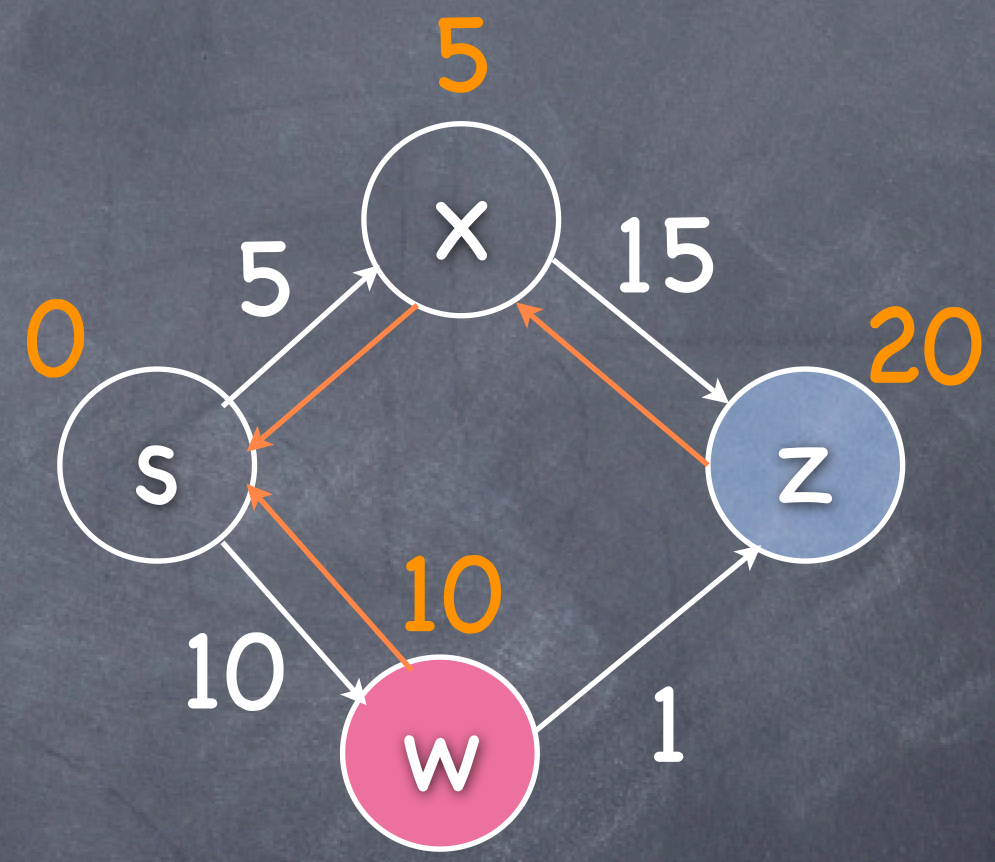

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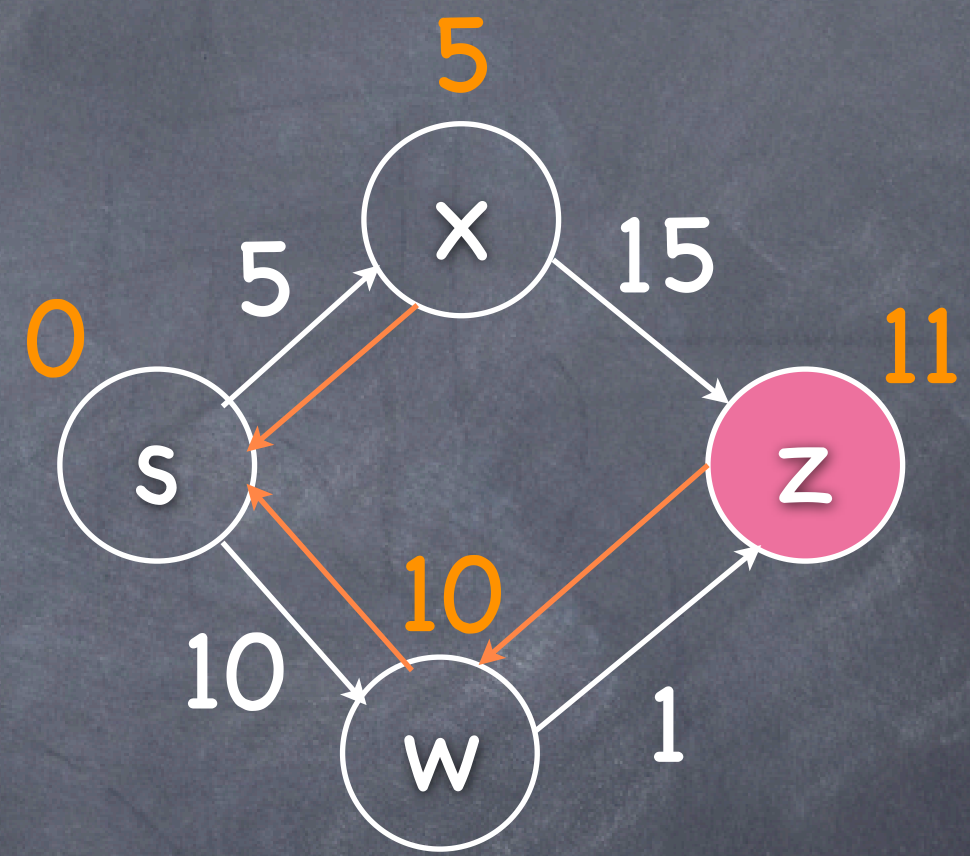

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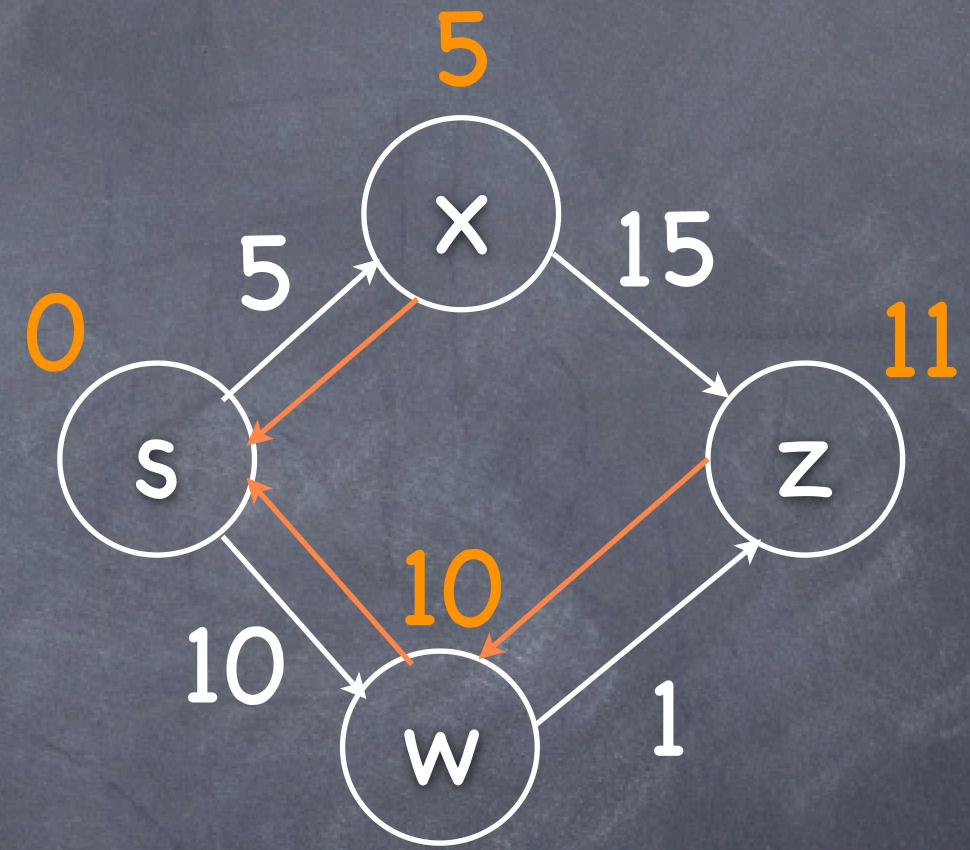


Straight Forward Implementation (1)

To node we add:

```
private int distance = Integer.MAX_VALUE;
private Node predecessor = null;
private boolean finalized = false;

public void init(boolean isSource){
    finalized = false;
    predecessor = null;
    distance = isSource? 0 :Integer.MAX_VALUE;
}

public boolean isFinal(){ return finalized; }

public void markAsFinal(){ finalized = true; }

public boolean isReachable(){
    return distance != Integer.MAX_VALUE; }

public boolean isActive(){
    return !isFinal() && isReachable();}
```

```
public Maybe<Path> getShortestPath(){...}

public void updateDistances(){
    for (Edge e : getOutgoingEdges()) {
        Node v = (Node) e.getTarget();
        if(!v.isFinal()){
            int alt = distance + e.getLength();
            if(alt < v.distance){
                v.distance = alt;
                v.predecessor = this;
            }
        }
    }
}
@Override
public int compareTo(Node o) {
    return distance - o.distance;
}
```

Straight Forward Implementation (2)

- Note that:
  - Instead of maintaining the set of final nodes, we maintain a finalized bit for each node. Otherwise, we need to pass too much information (the list of all final nodes) to Node.updateDistances().
  - distance, finalized and predecessor are only meaningful during an invocation of dijkstra(..).

Straight Forward Implementation (3)

To graph we add:

```java
public Map<Node, Maybe<Path>> dijkstra(Node source){
    // Initialize Dijkstra node extension
    for (Node n : getNodes()) {
        n.init(n == source);
    }
    // Compute shortest paths
    for(Node u = getClosestActiveNode();
            u != null;
            u = getClosestActiveNode()){
        u.markAsFinal();
        u.updateDistances();
    }
    // retrieve shortest paths
    Map<Node, Maybe<Path>> result = new ...;
    for (Node node : getNodes()) {
        result.put(node, node.getShortestPath());
    }
    return result;
}
```

```java
public Node getClosestActiveNode(){
    Collection<Node> activeNodes = getActiveNodes();
    if(activeNodes.size() == 0){
        return null;
    }else{
        return Collections.min(activeNodes);
    }
}

private Collection<Node> getActiveNodes(){
    List<Node> active = new ...;
    for (Node n : getNodes()) {
        if(n.isActive()){
            active.add(n);
        }
    }
    return active;
}
```

32:36:1152:public dijkstraaj.Graph$Node dijkstraaj.Graph.getClosestNonFinalNode()[0]
30:36:1080:public java.util.Collection dijkstraaj.Graph.getActiveNodes()[0]

Optimizations

- Analyzing the execution traces of our implementation we discover that the two methods getClosestActiveNode() and getActiveNodes() are invoked several times with the same graph object.
- We maintain a priority queue of nodes ordered by the node's shortest known distance from source and use it to speed up getClosestActiveNode().

Optimization Aspect

```
public aspect ActiveNodes
percflow(execution(public Map<Node, Maybe<Path>> dijkstra(Node))){
    //active nodes in the graph ordered by their distance from source
    private PriorityQueue<Node> activeNodes = new ...;

    after(Node n): call(public void markAsFinal()) && target(n){
        activeNodes.remove(n);
    }

    before(Node n): set(private int Node.distance) && target(n){
        if(n.isReachable()){
            activeNodes.remove(n);
        }
    }

    after(Node n): set(private int Node.distance) && target(n){
        if(n.isReachable()){
            activeNodes.add(n);
        }
    }

    Node around(): call(public Node getClosestActiveNode()){
        return activeNodes.peek();
    }
}
```

Why keeping the optimization separate?

- No need to change method signatures (what's the problem with changing method signatures?).
- Fewer things to keep in your head while:
  - Developing the algorithm.
  - Understanding/Maintaining the algorithm.
- Reduced scattering an tangling of optimization related code with the base program.
- Safety: Algorithm + Optimization Aspect $\simeq$ Algorithm

Changing Method Signatures

```
public Map<Node, Maybe<Path>> dijkstra(Node source){
 => private PriorityQueue<Node> activeNodes = new ...;
    // Initialize Dijkstra node extension
    for (Node n : getNodes()) {
        n.init(n == source);
    }
    // Compute shortest paths
 => for(Node u = activeNodes.peek();
            u != null;
 =>         u = activeNodes.peek()){
        u.markAsFinal();
=>      if(v.isReachable()){
=>          activeNodes.remove(u);
=>      }
*=>     u.updateDistances(activeNodes);
    }
    // retrieve shortest paths
    Map<Node, Maybe<Path>> result = new ...;
    for (Node node : getNodes()) {
        result.put(node, node.getShortestPath());
    }
    return result;
}
```

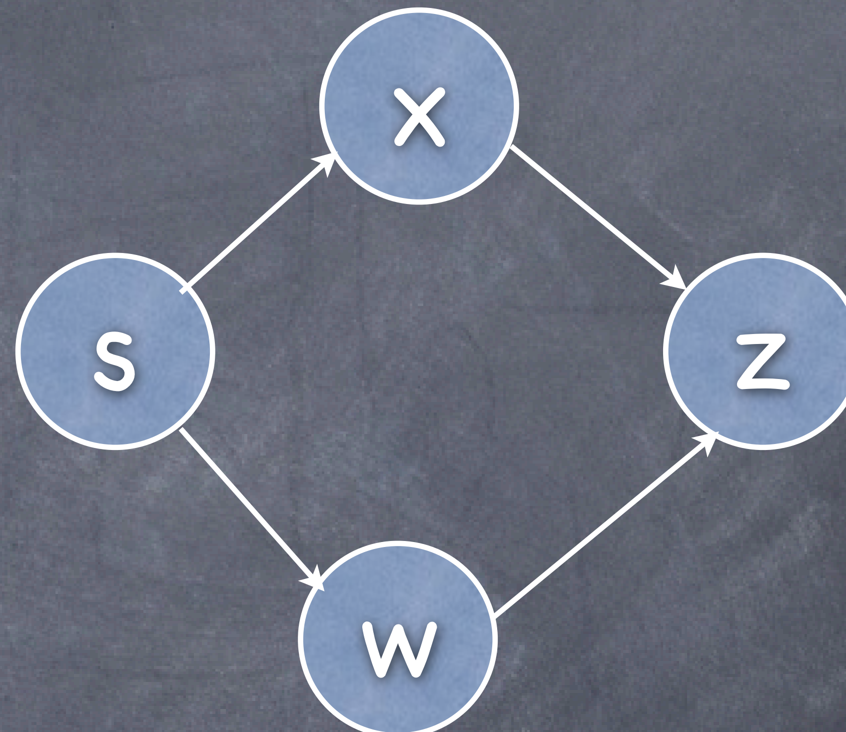
```
=> public void updateDistances
(PriorityQueue<Node>  activeNodes){
    for (Edge e : getOutgoingEdges()) {
        Node v = (Node) e.getTarget();
        if(!v.isFinal()){
            int alt = distance + e.getLength()
            if(alt < v.distance){
=>              if(v.isReachable()){
=>                  activeNodes.remove(v);
=>              }
                v.distance = alt;
=>              if(v.isReachable()){
=>                  activeNodes.add(v);
=>              }
                v.predecessor = this;
            }
        }
    }
}

=> public void init(boolean isSource,
PriorityQueue<Node>  activeNodes){
    finalized = false;
    predecessor = null;
=>  if(isReachable()){
=>      activeNodes.remove(this);
=>  }
    distance = isSource? 0 :Integer.MAX_VALUE;
=>  if(isReachable()){
=>      activeNodes.add(this);
=>  }
}
```

Safety

- Algorithm + Optimization Aspect $\simeq$ Algorithm
- What if you forgot one of the lines related to optimization?
- Unit tests can catch the problem, but you'll get a single bit of information.
- We have a tool that monitors the execution of optimization aspects and notifies you right after the optimization aspects first derails the algorithm rather than when the algorithm finishes.

Topological Ordering

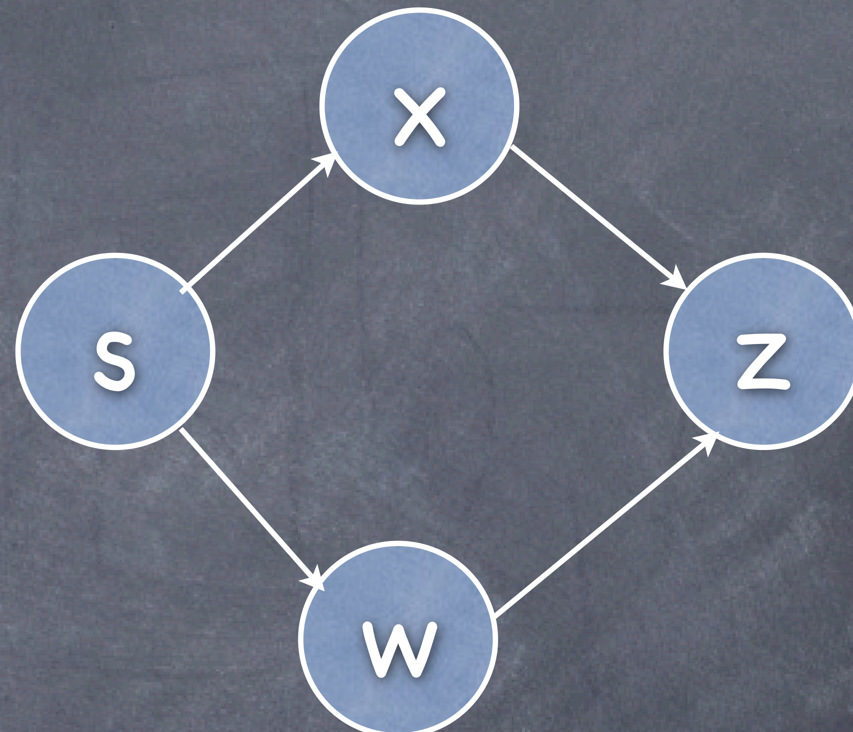
- Given a graph (g), find an ordering of its nodes such that node (a) comes before node (b) if there is a path from a to b.



- <s,x,z,w> ?
- <s,x,w,z> ?
- <s,w,x,z>?

Topological Ordering

```
public Maybe<List<Node>> topord(){
    List<Node> orderedNodes = new ...;
    for(Maybe<Node> mbNode = getSourceNode();
            mbNode.isSome();
            mbNode = getSourceNode()){
        orderedNodes.add(mbNode.get());
        remove(mbNode.get());
    }
    if(getNumNodes() > 0 ){
        return new None<List<Node>>();
    }
    return new Some<List<Node>>(orderedNodes);
}

public Maybe<Node> getSourceNode(){
    for (Node n : getNodes()) {
        if(n.getPredCount() == 0){
            return new Some<Node>(n);
        }
    }
    return new None<Node>();
}
```




```
public int getPredCount(){
    int predCount = 0;
    for (Node n  : getEnclosingGraph().getNodes()) {
        if(n.hasSuccessor(this)) predCount++;
    }
    return predCount;
}
```

Topological Ordering

```
public Maybe<List<Node>> topord(){
    List<Node> orderedNodes =
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    for(Maybe<Node> mbNode = getSourceNode();
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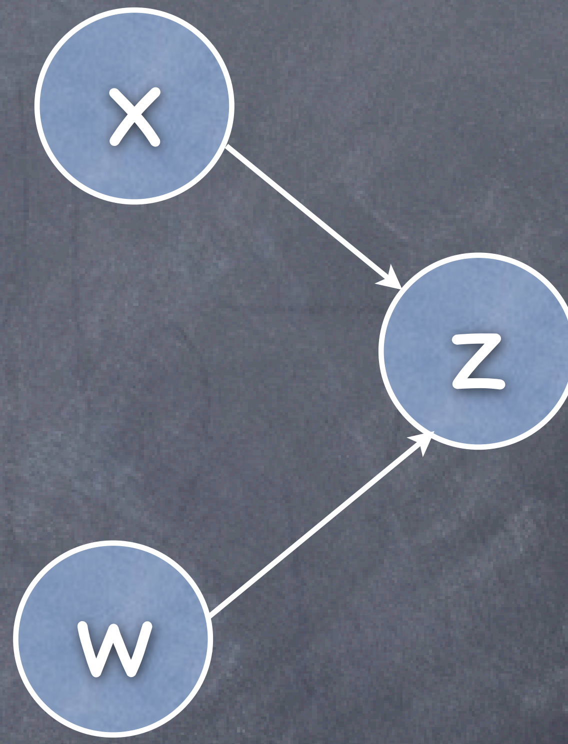


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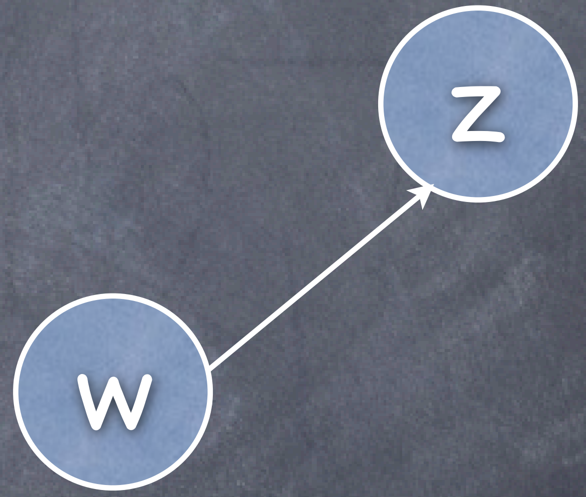


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public int getPredCount(){
    int predCount = 0;
    for (Node n  : getEnclosingGraph().getNodes()) {
        if(n.hasSuccessor(this)) predCount++;
    }
    return predCount;
}
```

- The graph is gone!
  - Mark nodes as removed rather than actually removing them.
  - Graph accessors need to be modified to take those marks into account during (in the control flow of) the execution of topord()
- Sounds like an aspect. Described as a modification to an existing component (the graph).

70:33:2310:public lib.Maybe topsort.Graph.getSourceNode()[0]
29:77:2233:public int topsort.Graph$Node.getPredCount()[0]

Not Optimal

- getSourceNode() and getPredCount() are invoked several times with the same arguments.
- Maintain the list of current source nodes. Upon removing a node
  - remove it from the list.
  - potentially add its successors to the list.
- Maintain the count of predecessors. Upon removing a node, decrement the predecessors count of its successors.

getSourceNode()

```
public aspect SrcNode {
    private List<Node> Graph.sourceNodes = null;
    //Memoization + Eager initialization
    Maybe<Node> around(Graph g): execution(public Maybe<Node> getSourceNode()) && target(g){
        if(g.sourceNodes == null){
            g.sourceNodes = new ArrayList<Node>();
            for (Node n : g.getNodes()) {
                if(n.getPredCount()==0){
                    g.sourceNodes.add(n);
                }
            }
        }
        if(g.sourceNodes.size() == 0){
            return new None<Node>();
        }else{
            return new Some<Node>(g.sourceNodes.get(0));
        }
    }
    //Maintenance
    void around(Graph g, Node n): execution(public void remove(Node)) && target(g) && args(n){
        List<Node> successorsOfToBeRemovedNode = new ArrayList<Node>(n.getSuccessors());
        proceed(g,n);
        for (Node succ : successorsOfToBeRemovedNode) {
            if(succ.getPredCount() == 0){
                g.sourceNodes.add(succ);
            }
        }
        g.sourceNodes.remove(n);
    }
}
```

getPredCount()

```
public aspect Preds {

    private int Node.predCount = -1;

    //Memoization + Eager initialization
    int around(Node node): execution(public int getPredCount(..)) && target(node){
        if(node.predCount == -1){
            for (Node n  : node.getEnclosingGraph().getNodes()) {
                n.predCount = 0;
            }
            for (Node n  : node.getEnclosingGraph().getNodes()) {
                for (Node succ : n.getSuccessors()) {
                    succ.predCount++;
                }
            }
        }
        return node.predCount;
    }

    //Maintenance
    before(Node n): execution(private void removeAllSuccessors(..)) && target(n){
        for (Node succ : n.getSuccessors()) {
            succ.predCount--;
        }
    }
}
```

To Take Home

- Factor you program into components and aspects.
- Don’t refactor your program into aspects, it’s harder that way.
- Figure out aspects from the requirements.
- Optimizations **<u>should</u>** be factored out into aspects.