Don’t Mind the Gap:
Bridging Network-wide Objectives and Device-level Configurations

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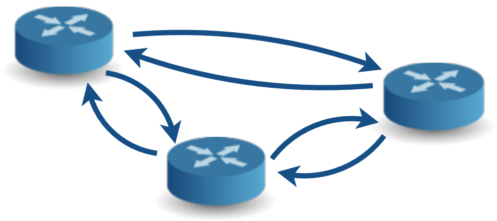
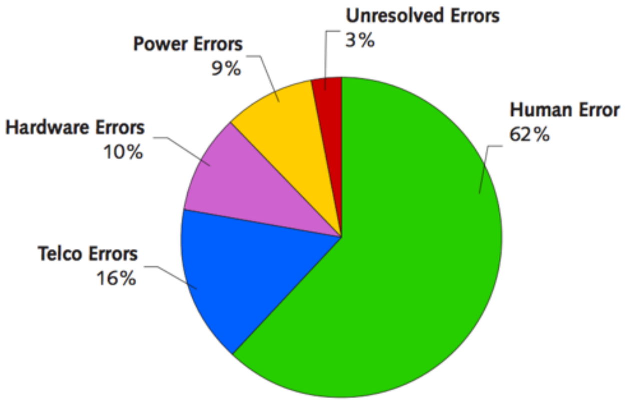
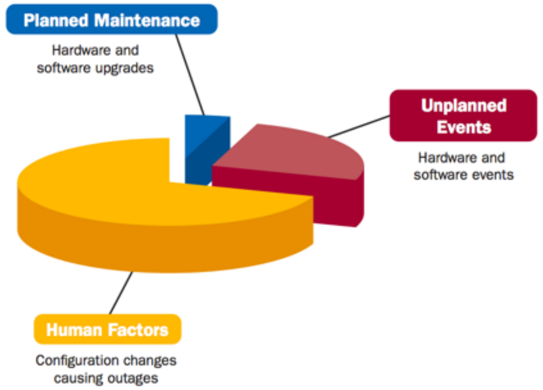
David Walker (Princeton)



Configuring Networks is Error-Prone





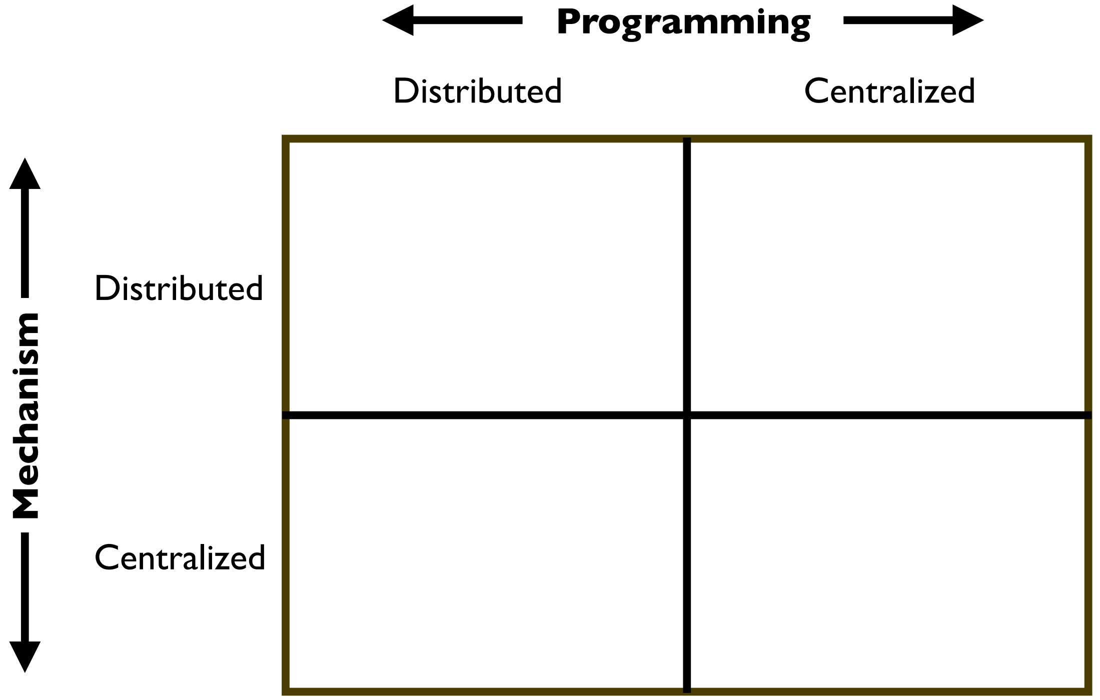
~60% of network downtime is caused by human error

-Yankee group 2002

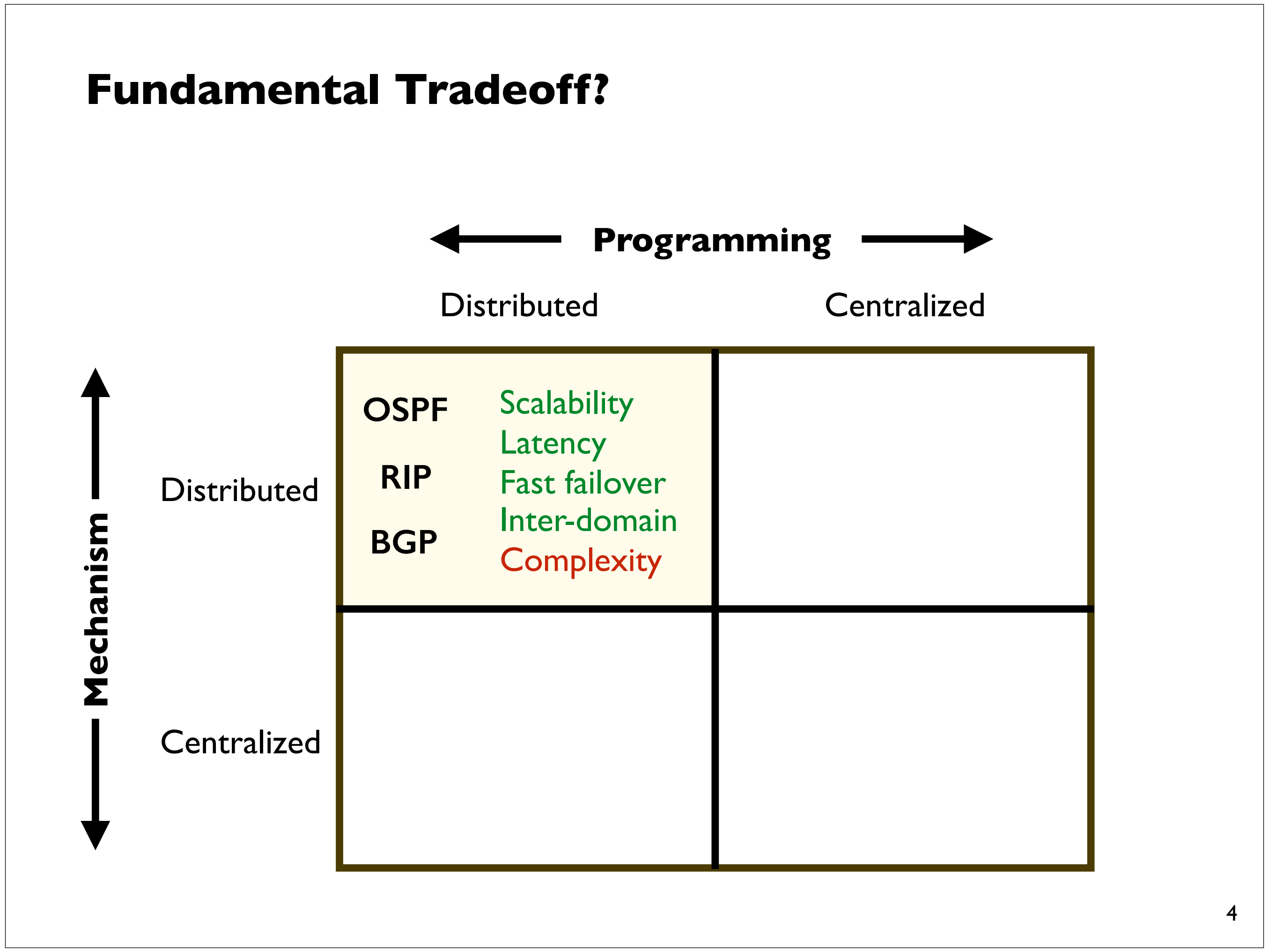
50-80% of outages from configuration changes

-Juniper 2008

Fundamental Tradeoff?



Distinguish what each means



Fundamental Tradeoff?

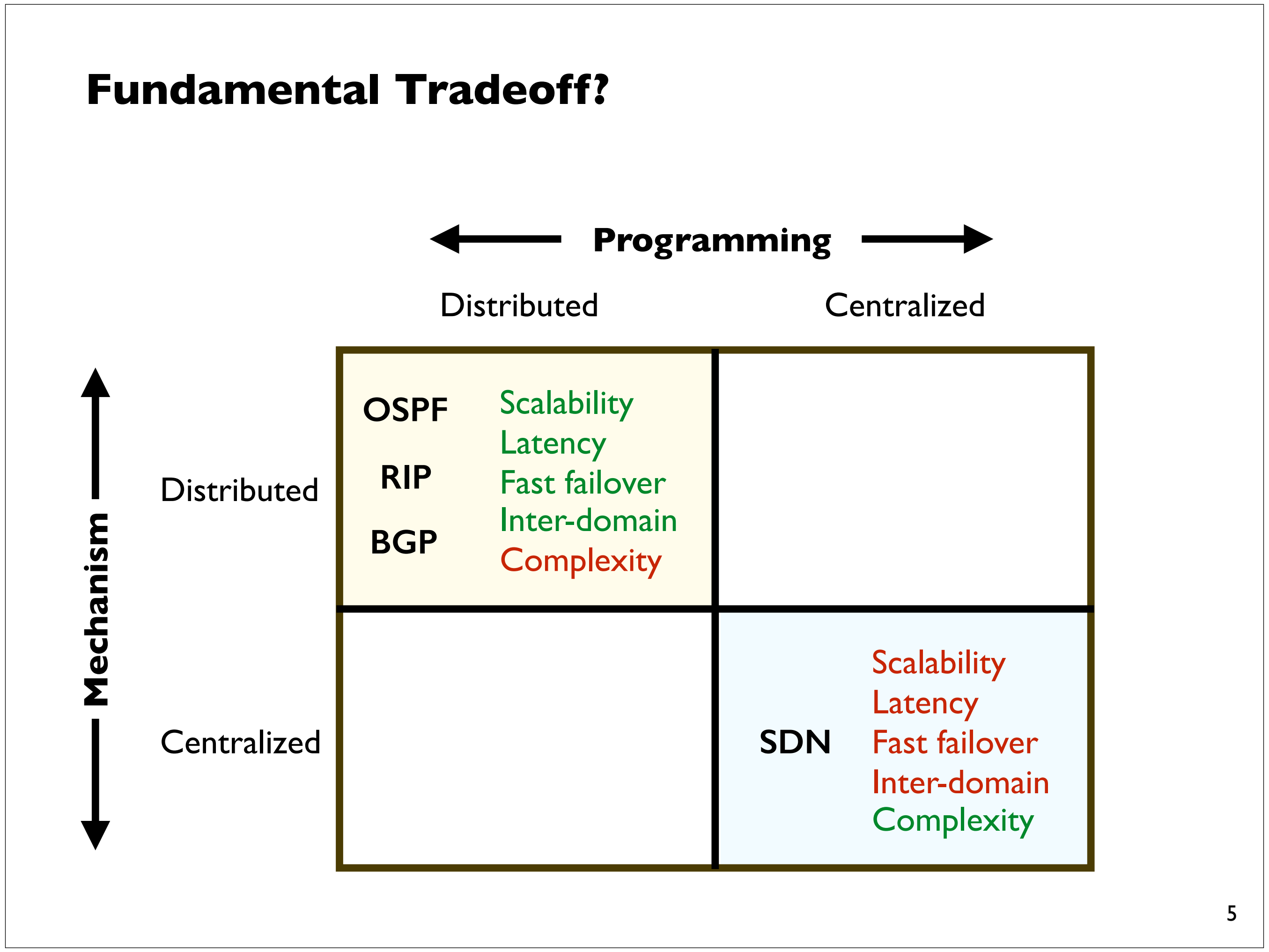
← Programming →

Mechanism	Distributed	Centralized
Distributed	OSPF RIP BGP Scalability Latency Fast failover Inter-domain Complexity	
Centralized		

Explain why BGP/OSPF fall into this category

Explain why SDN falls into this category (e.g., with concrete example: OpenDaylight)

Go through each property in detail for both cases



Fundamental Tradeoff?

Programming

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Centralized		SDN Scalability Latency Fast failover Inter-domain Complexity

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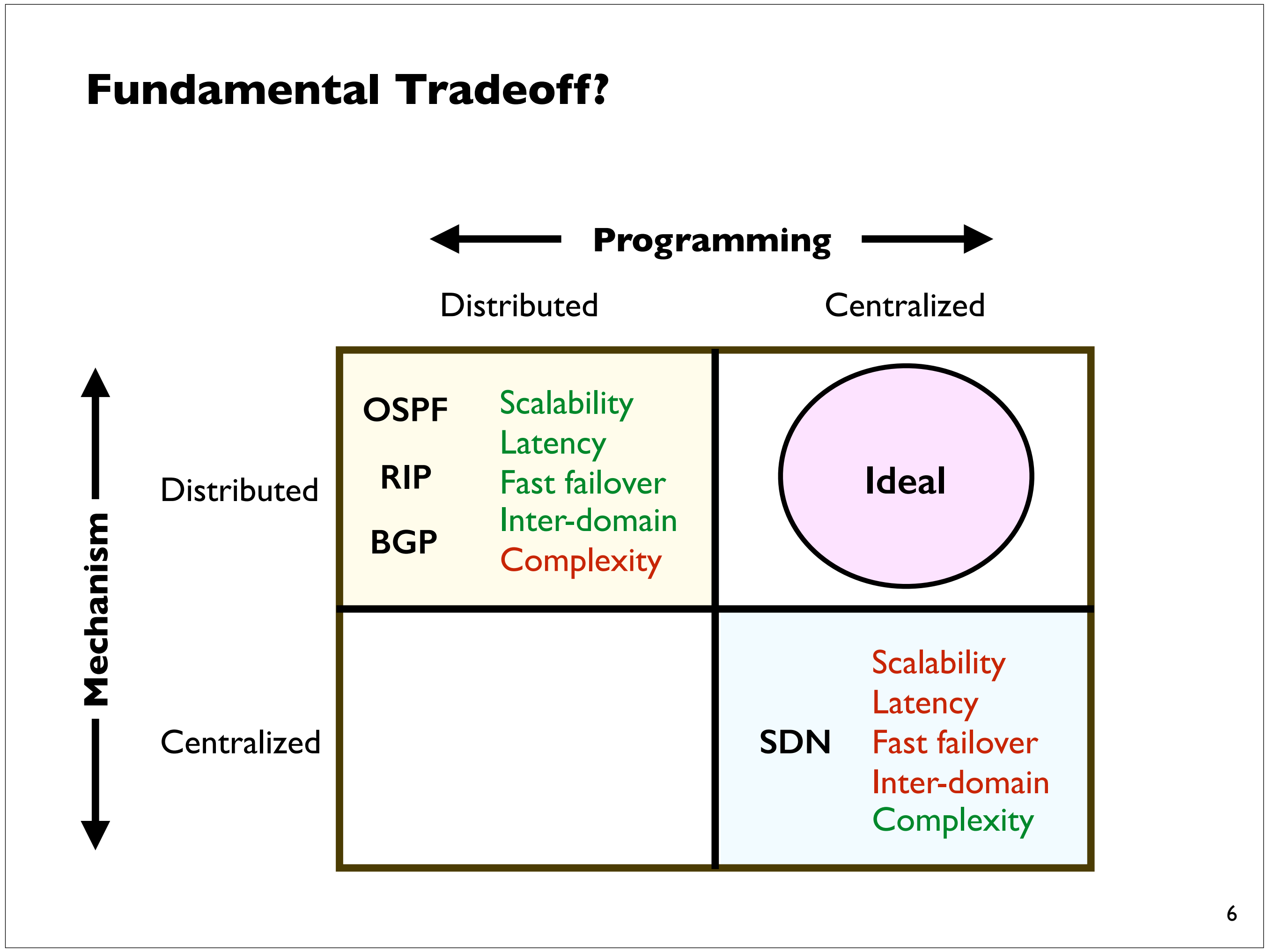

Fundamental Tradeoff?

		Programming	
		Distributed	Centralized
Mechanism	Distributed	OSPF RIP BGP Scalability Latency Fast failover Inter-domain Complexity	Ideal
	Centralized		SDN Scalability Latency Fast failover Inter-domain Complexity

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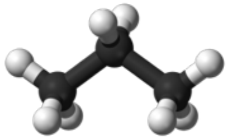
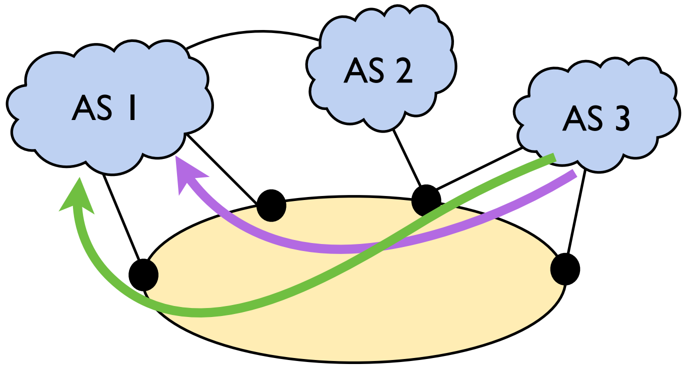
Propane System



I) Language for expressing high-level operator objectives with:

- **Network-wide** programming abstraction
- Uniform abstractions for **intra**- and **inter**-domain routing
- Path **constraints** and **preferences** in case of failures



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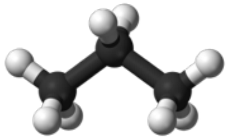
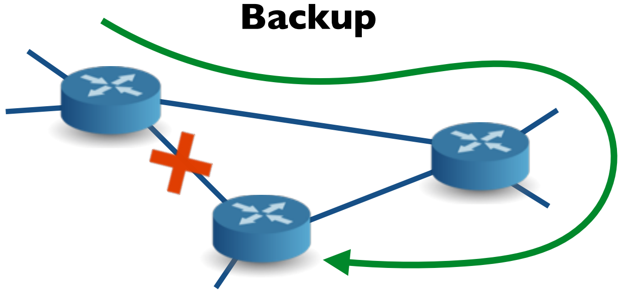


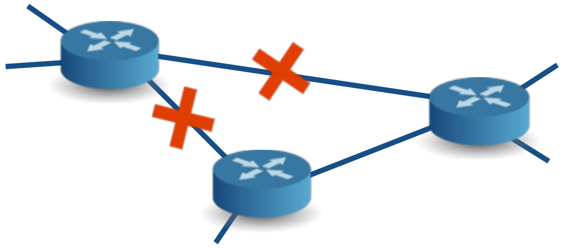
2) Compiler to generate a low-level distributed implementation

- Efficient algorithms to synthesize BGP configs
- Static analysis guarantees policy-compliance
- Policy-compliance holds under all failures

Backup



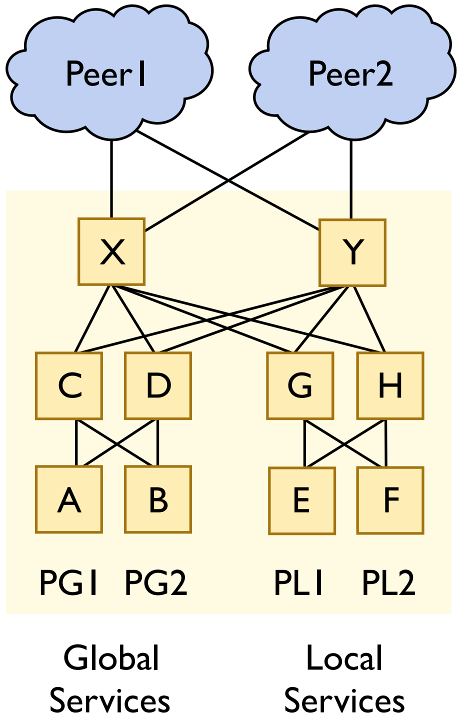
Network partition — drop

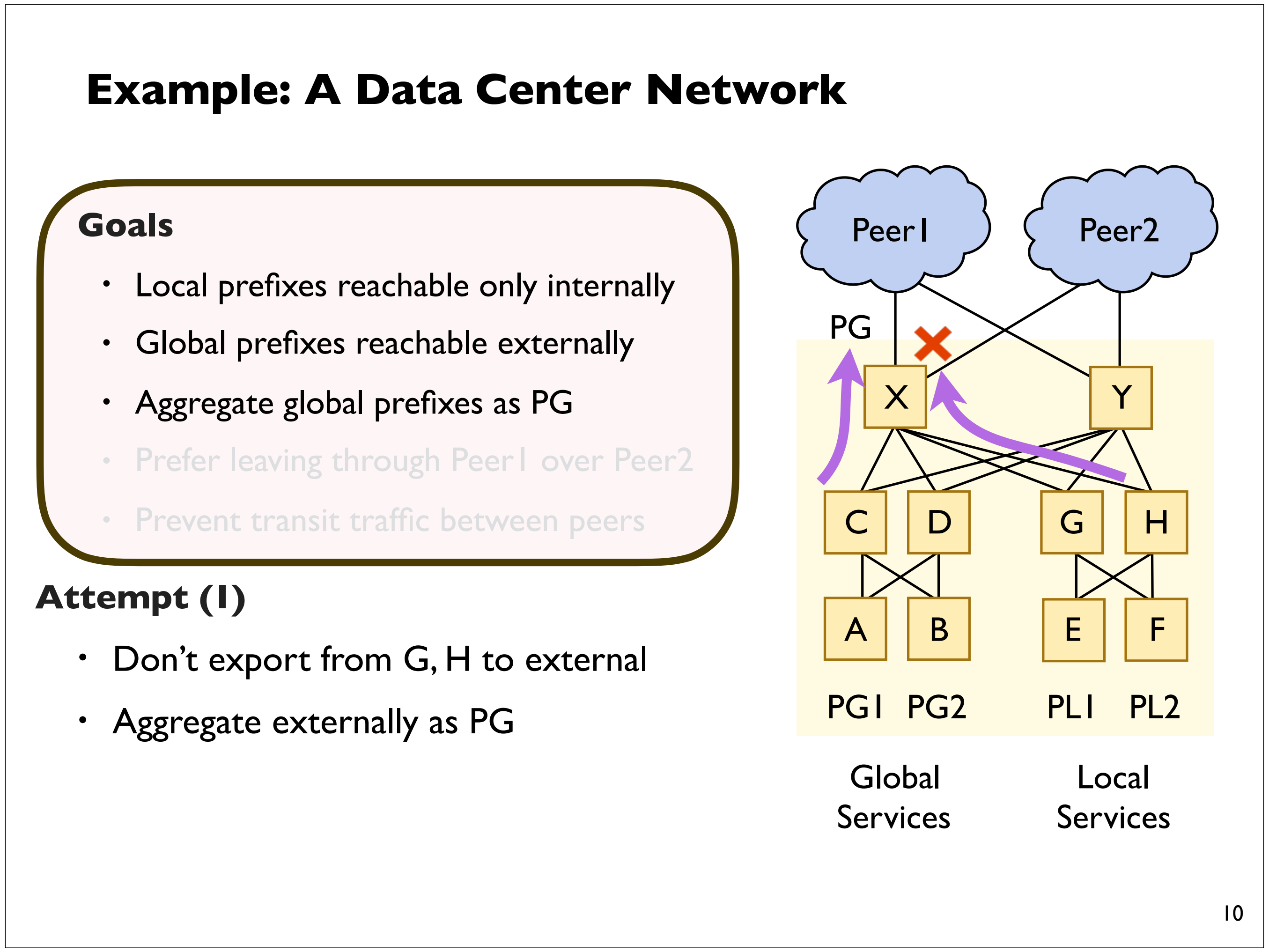


Example: A Data Center Network

Goals

- Local prefixes reachable only internally
- Global prefixes reachable externally
- Aggregate global prefixes as PG
- Prefer leaving through Peer1 over Peer2
- Prevent transit traffic between peers





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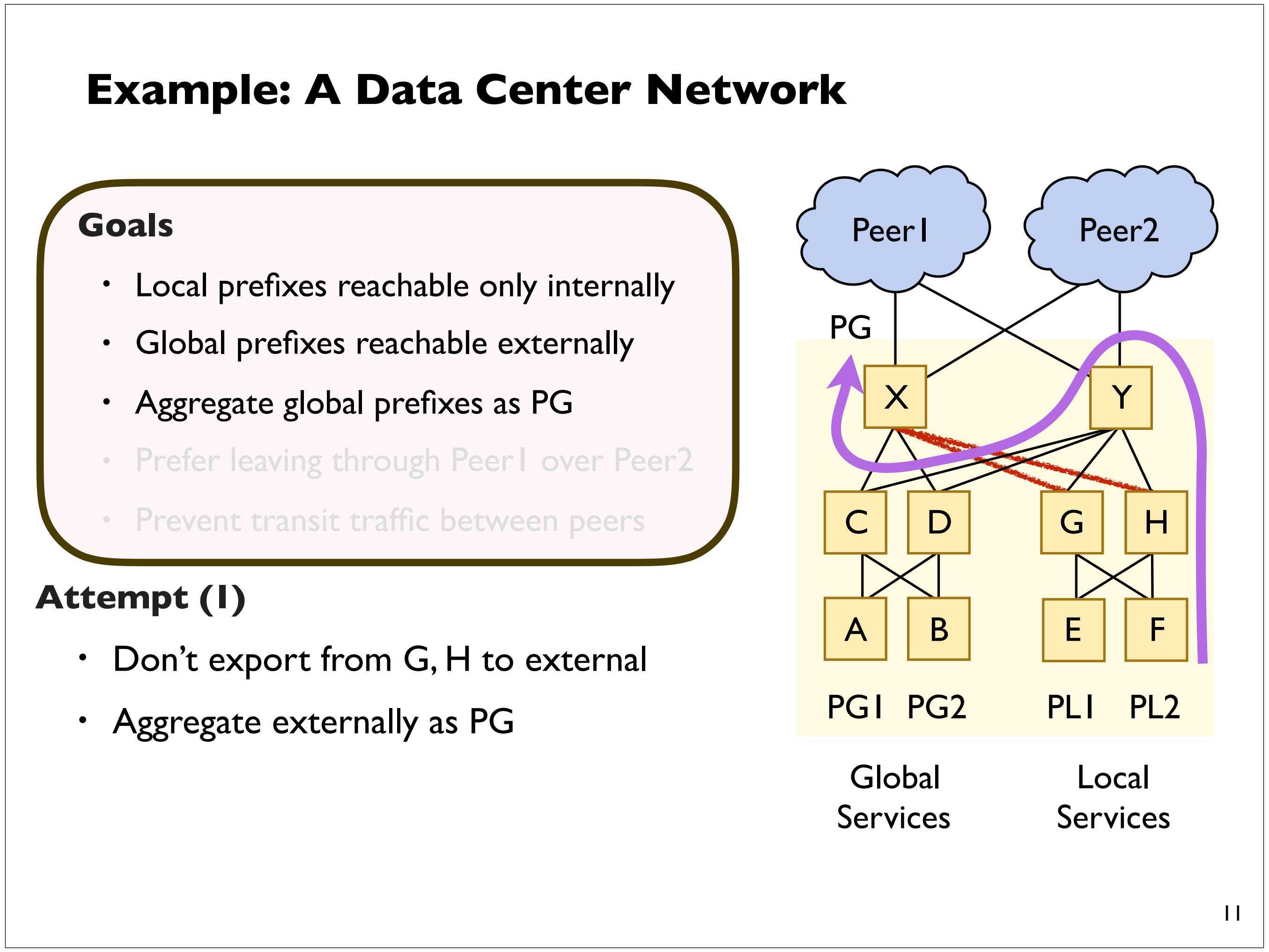
Attempt (1)

- Don’t export from G, H to external
- Aggregate externally as PG

Be clear about the direction of traffic vs. advertisement



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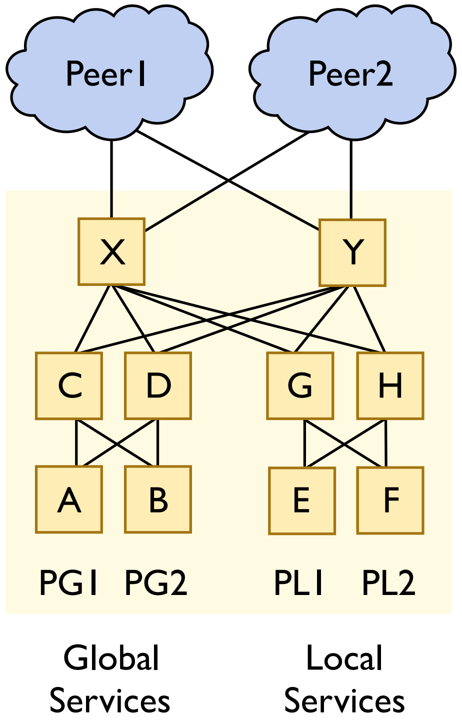
- **X,Y block routes through each other**



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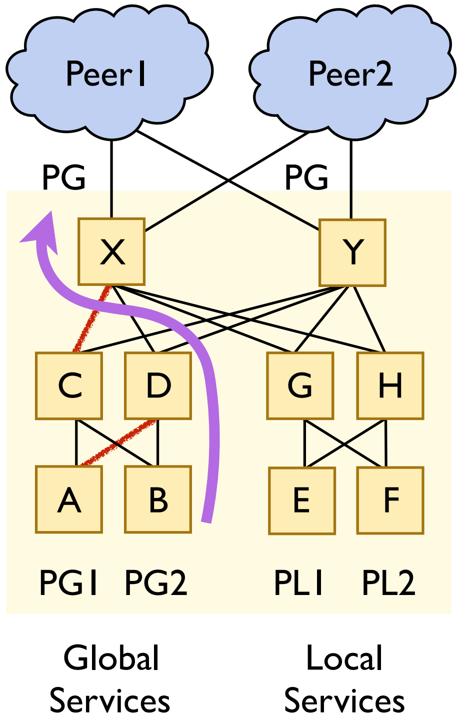

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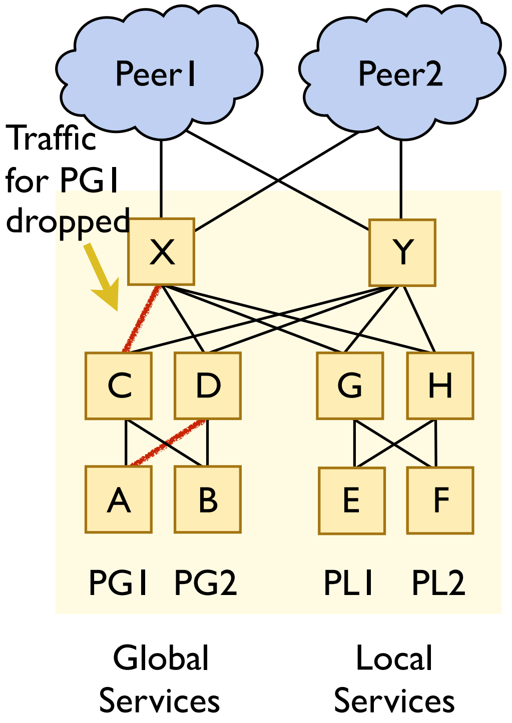

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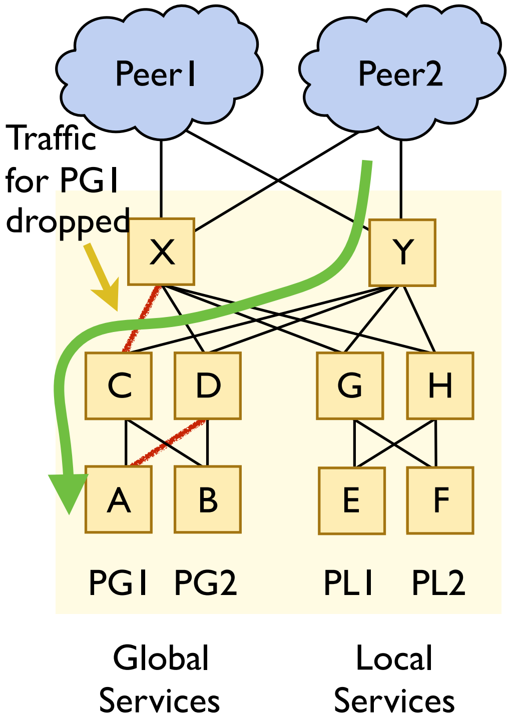

Aggregation-Induced Black Hole!

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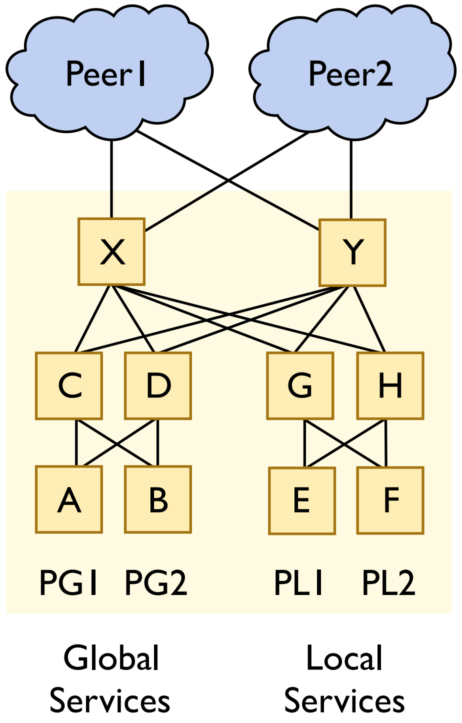

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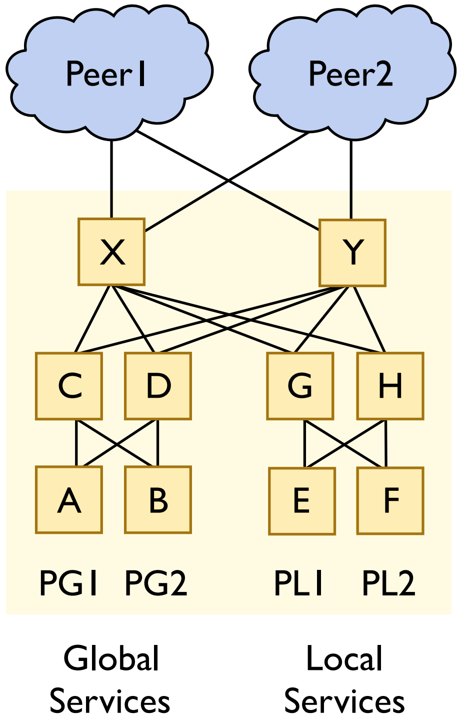
```
define Ownership =
 {PG1  => end(A)
  PG2  => end(B)
  PL1  => end(E)
  PL2  => end(F)
  true => exit(Peer1 >> Peer2)}
```



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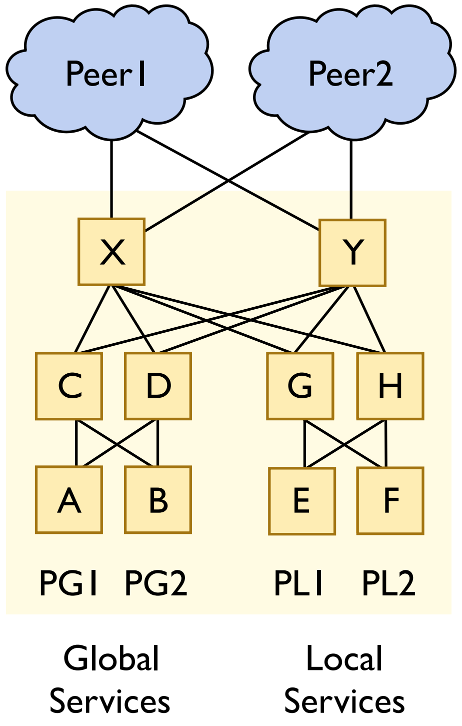
define Locality =
 {PL1 | PL2 => internal}
```



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define transit(X,Y) =
 enter(X|Y) and exit(X|Y)
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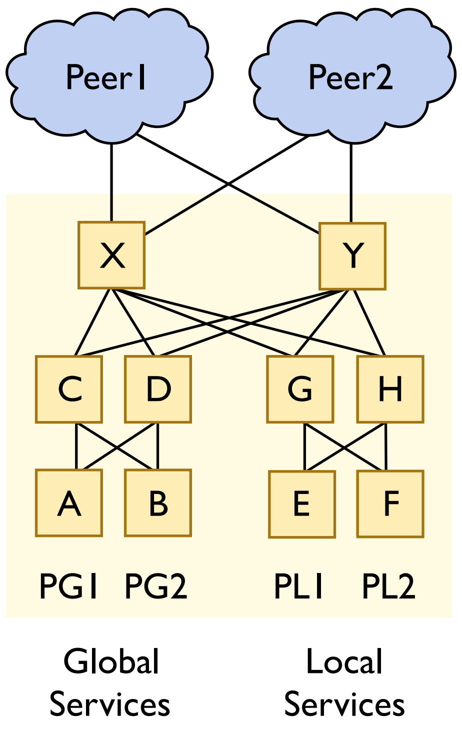

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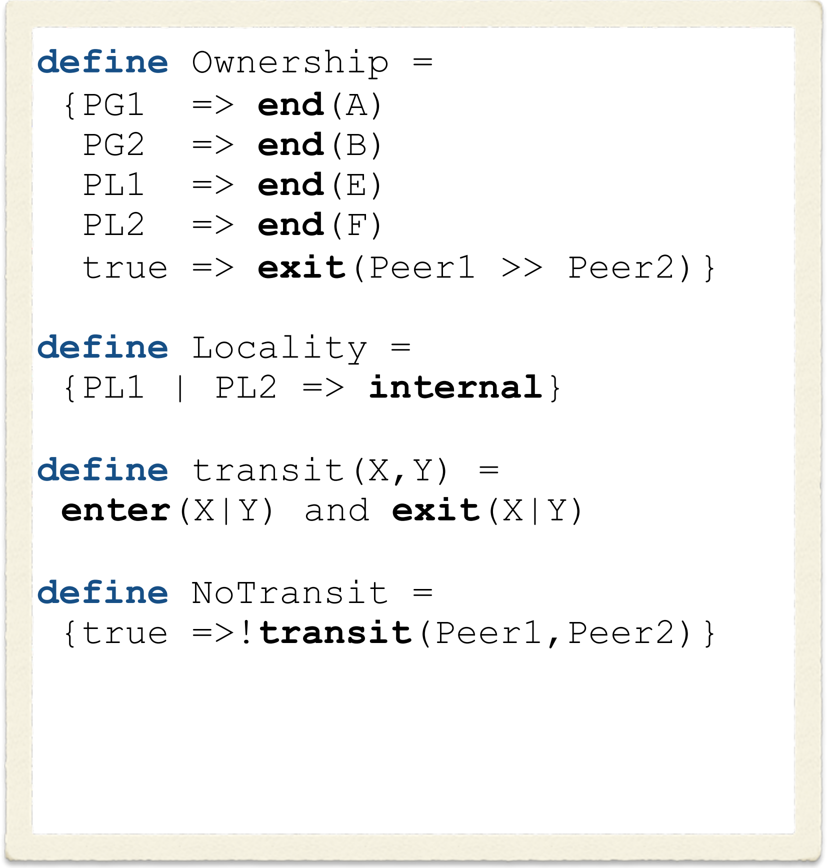

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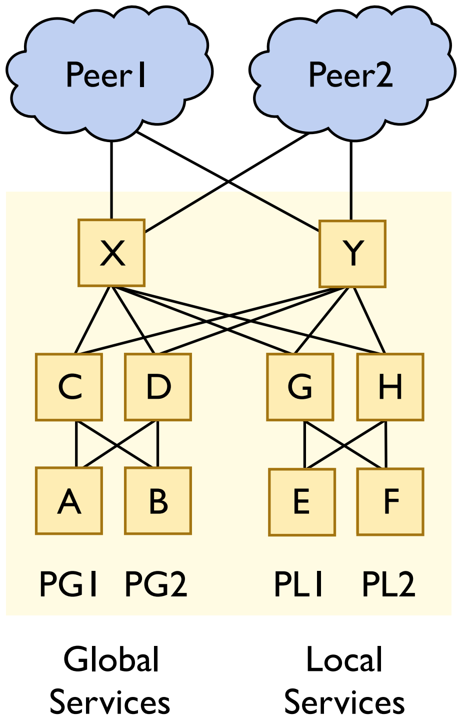
define NoTransit =
 {true =>!transit(Peer1,Peer2)}
```



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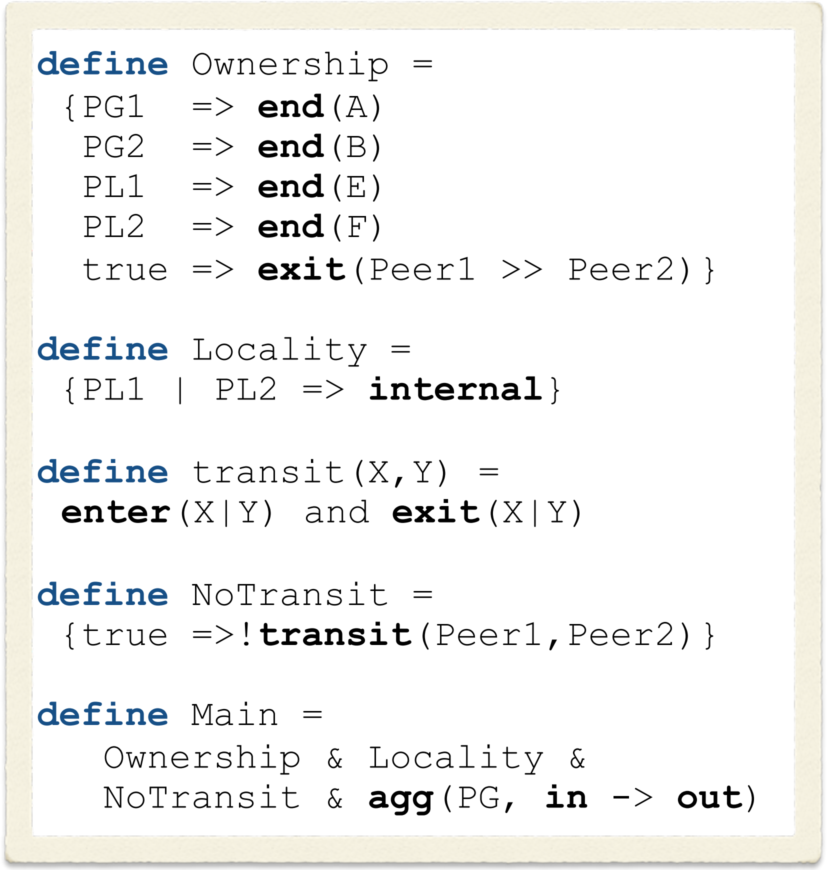

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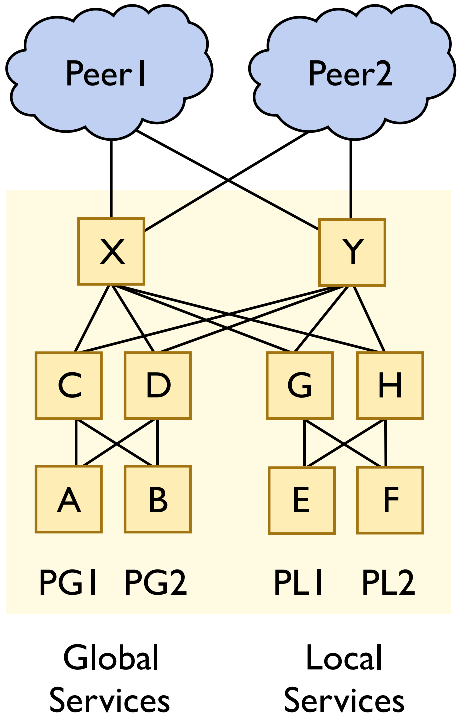
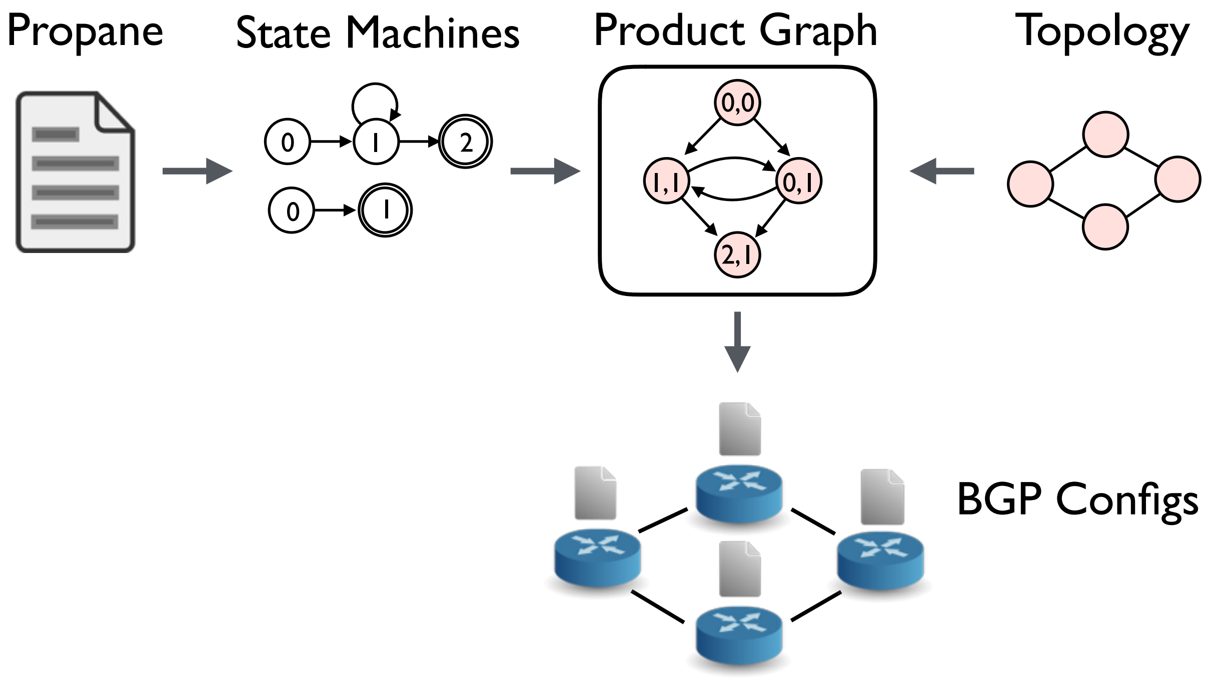
define NoTransit =
 {true =>!transit(Peer1,Peer2)}

define Main =
   Ownership & Locality &
   NoTransit & agg(PG, in -> out)
```



Compilation



Propane

State Machines

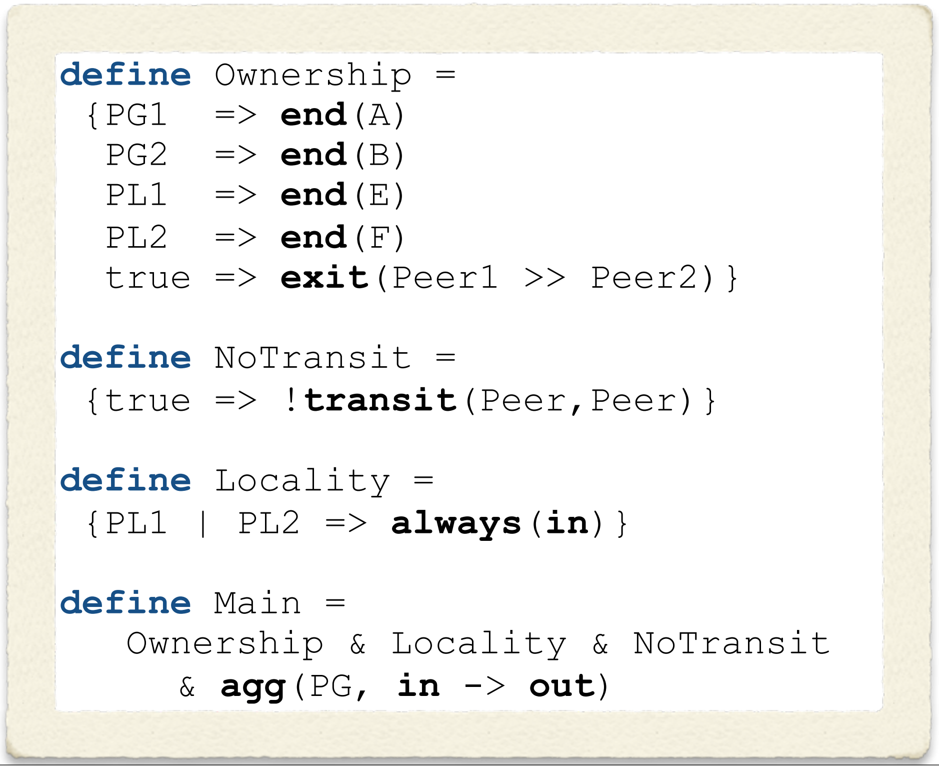
Product Graph

Topology

BGP Configs

Propane Regular IR

Step 1: Combine modular constraints



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 {PG1   => end(A)
  PG2   => end(B)
  PL1   => end(E)
  PL2   => end(F)
  true  => exit(Peer1 >> Peer2)}

define NoTransit =
 {true => !transit(Peer,Peer)}

define Locality =
 {PL1 | PL2 => always(in)}

define Main =
   Ownership & Locality & NoTransit
     & agg(PG, in -> out)
```

Propane Regular IR

Prefix-by-prefix intersection of constraints

```
PG1  => !transit(Peer,Peer) & end(A)
PG2  => !transit(Peer,Peer) & end(B)
PL1  => !transit(Peer,Peer) & internal & end(E)
PL2  => !transit(Peer,Peer) & internal & end(F)
true => !transit(Peer,Peer) & exit(Peer1 >> Peer2)
```

Propane Regular IR

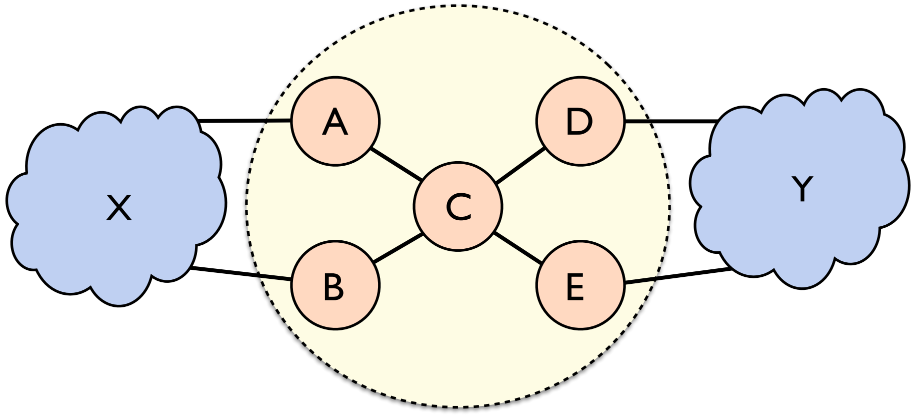
TODO: yellow obscures text

Single prefix

Prefix-by-prefix intersection of constraints

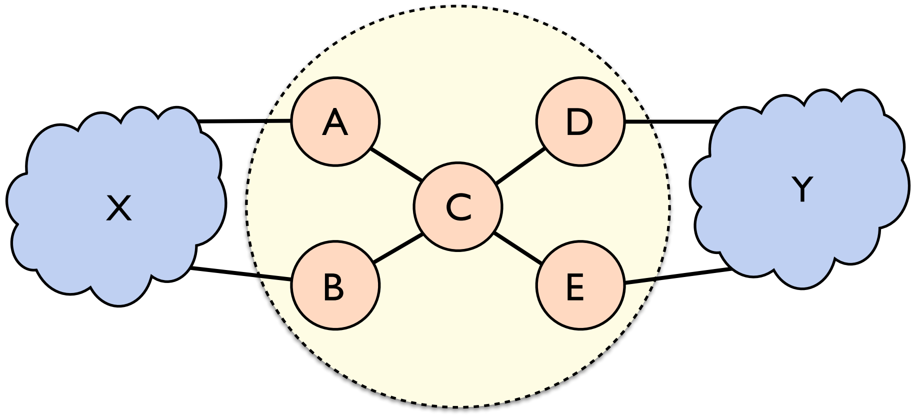
```
PG1  => !transit(Peer,Peer) & end(A)
PG2  => !transit(Peer,Peer) & end(B)
PL1  => !transit(Peer,Peer) & internal & end(E)
PL2  => !transit(Peer,Peer) & internal & end(F)
true => !transit(Peer,Peer) & exit(Peer1 >> Peer2)
```

Compilation: A simple Example



```
end(Y) & (path(A,C,D) >> any)
```

Compilation: A simple Example

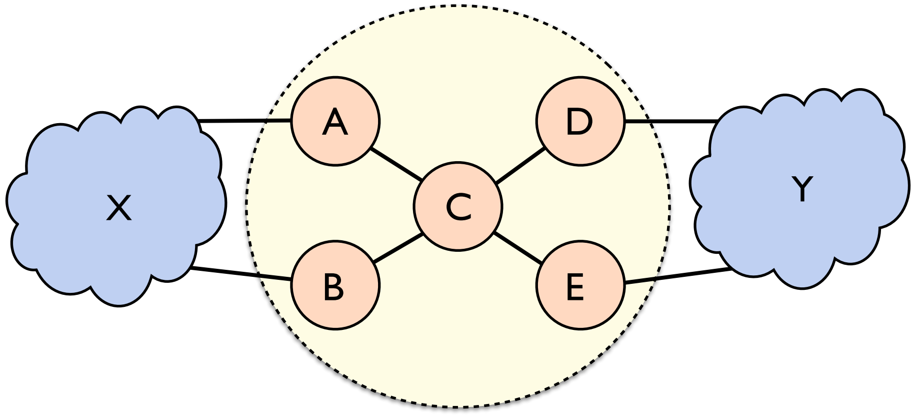


```
end(Y) & (path(A,C,D) >> any)
```

Distribute Preferences

```
(end(Y) & path(A,C,D)) >> (end(Y) & any)
```

Compilation: A simple Example



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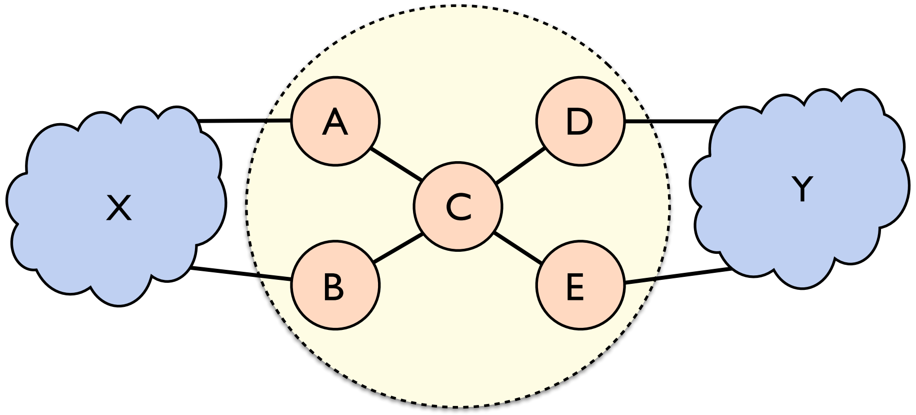
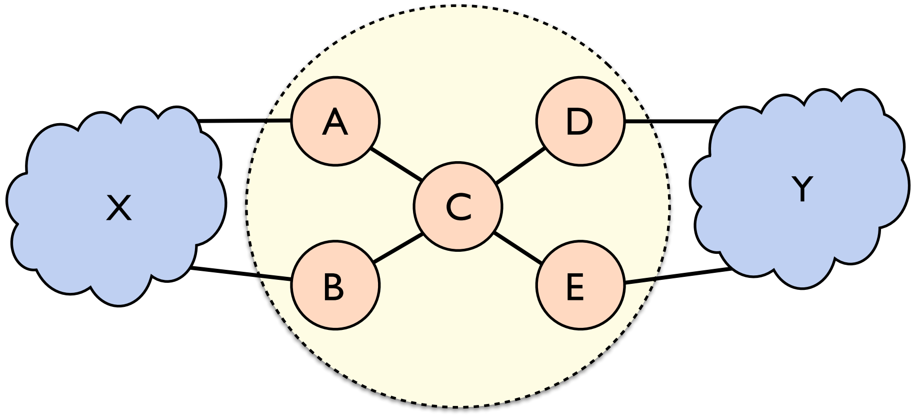


```
(end(Y) & path(A,C,D)) >> (end(Y) & any)
```

Convert to Regex

```
XACDY >> (Σ*)Y
```

Reversed Automata from Policies



Policy:

1. XACDY

2. (Σ*)Y

Be clear about the direction of traffic vs. advertisement

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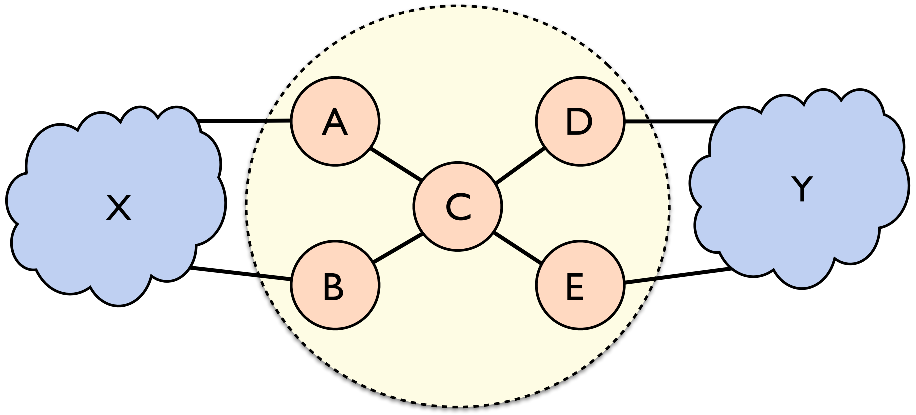

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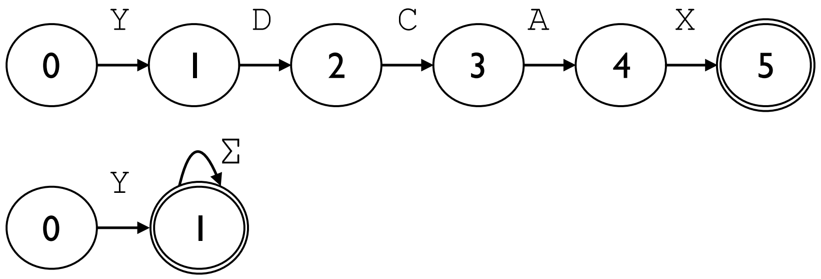

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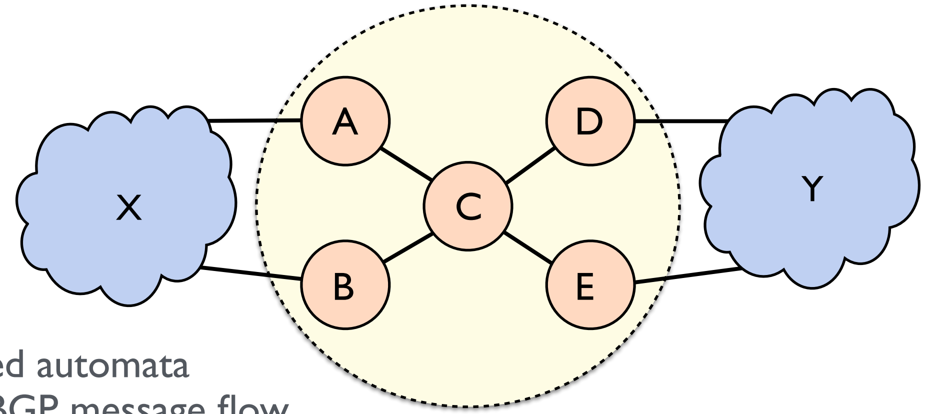

Reversed automata tracks BGP message flow

Policy:

```
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2. (Σ*)Y
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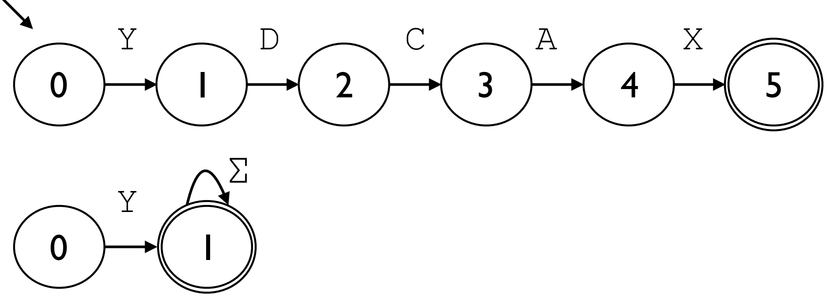
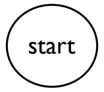
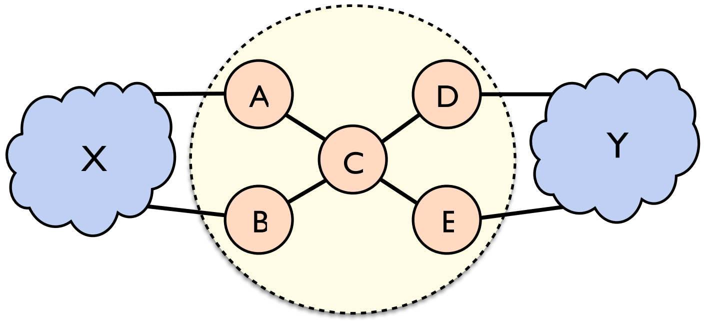
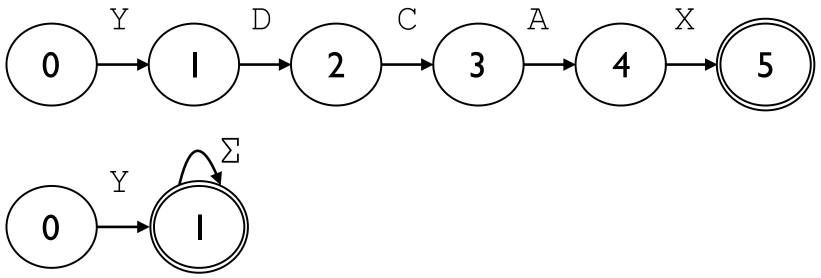


Constructing the Product Graph (PG)







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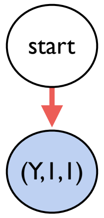

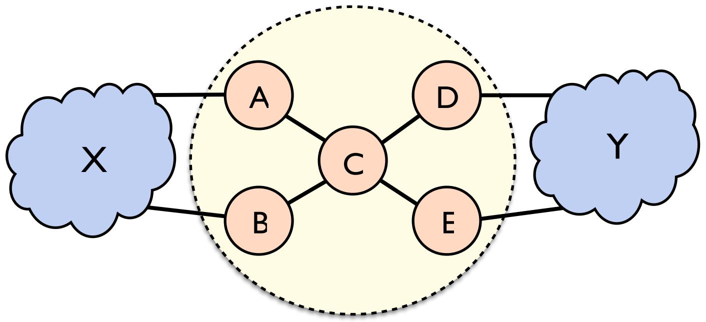

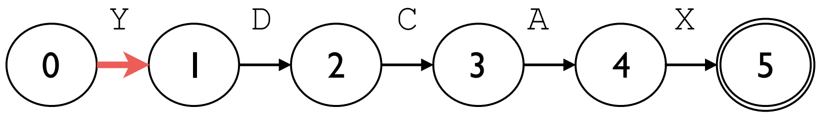

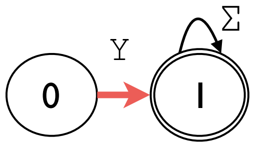

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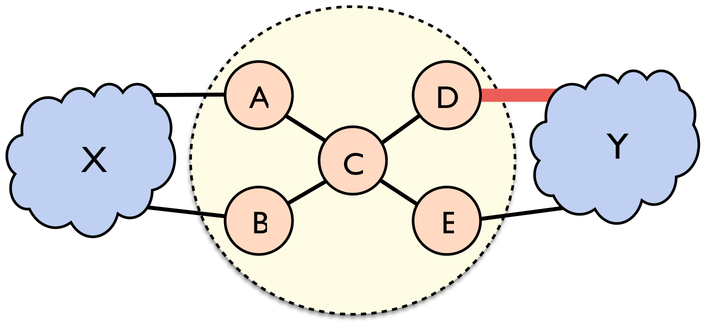

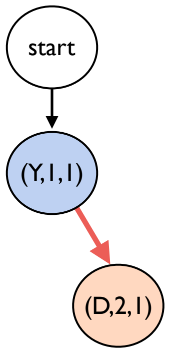

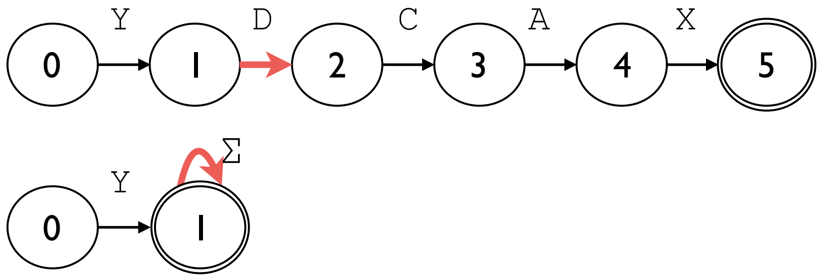

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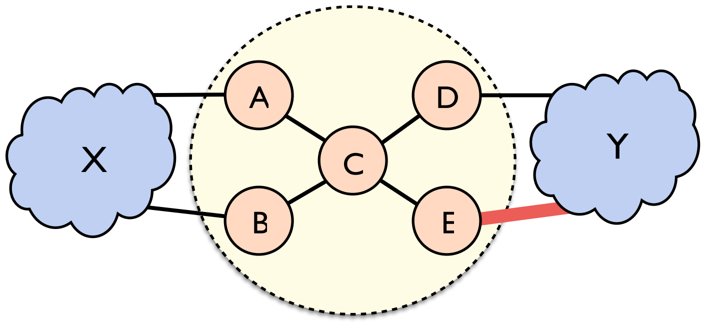
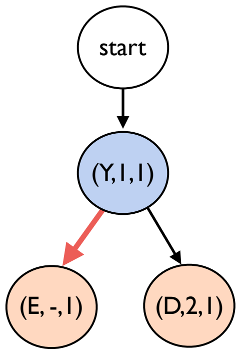
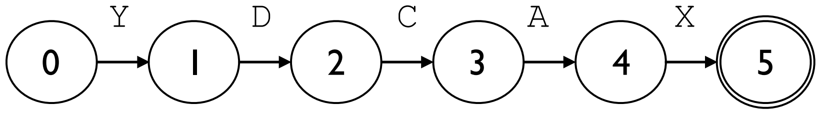
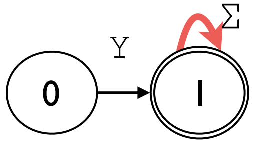
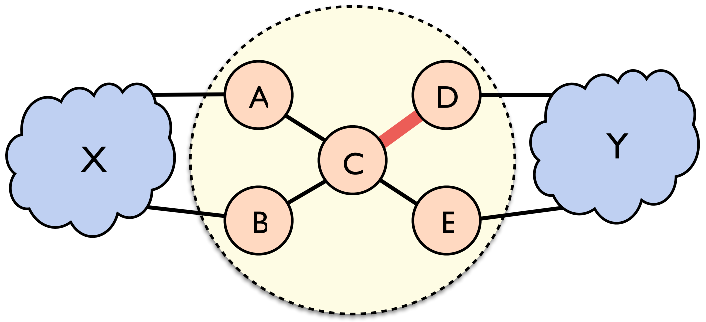


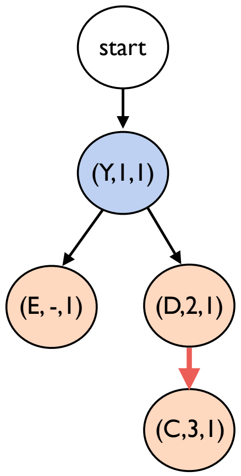


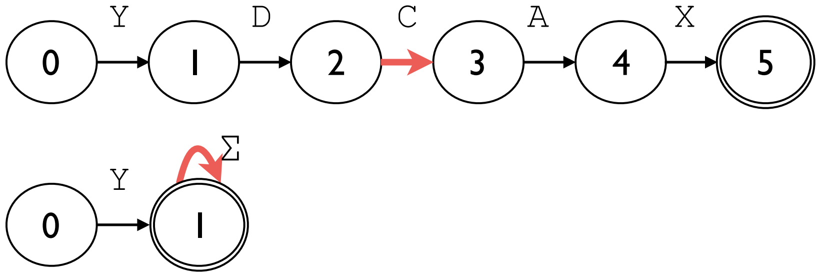




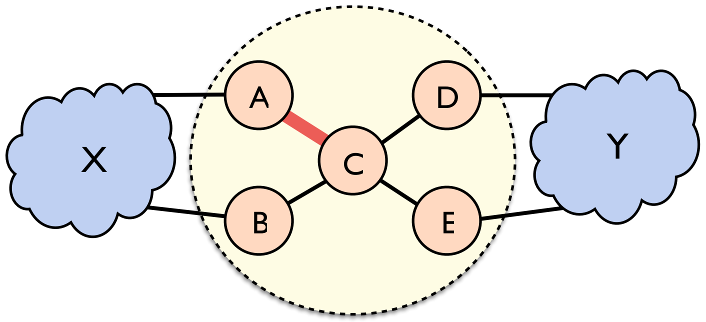
Constructing the Product Graph (PG)

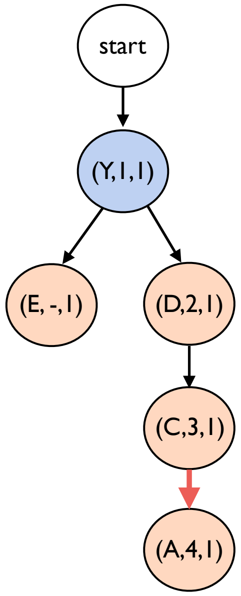


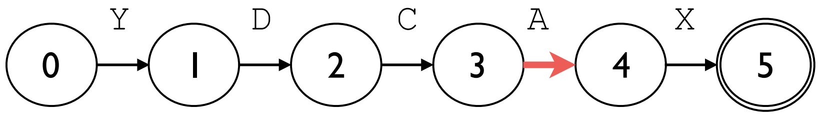


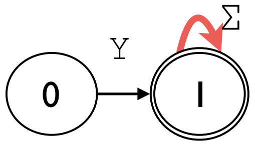


Constructing the Product Graph (PG)

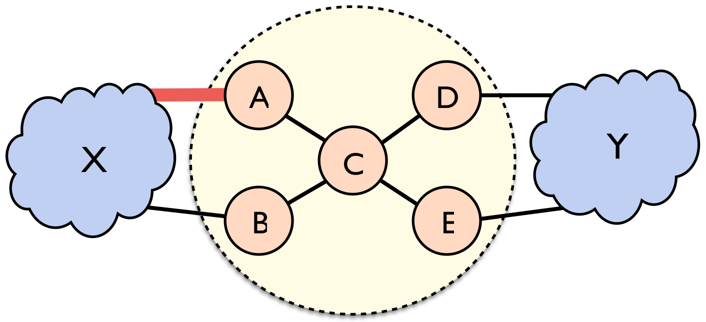


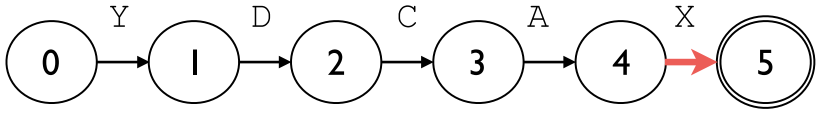


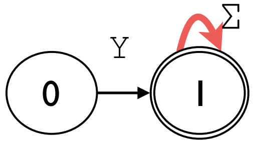


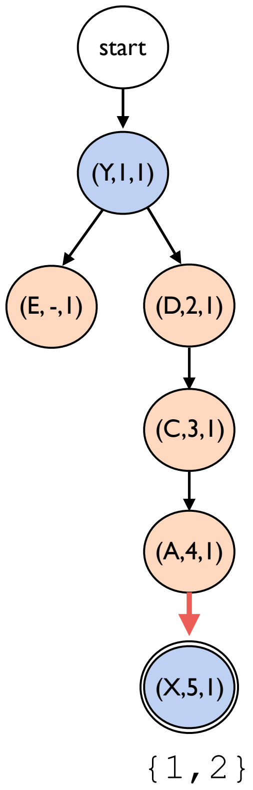


Constructing the Product Graph (PG)

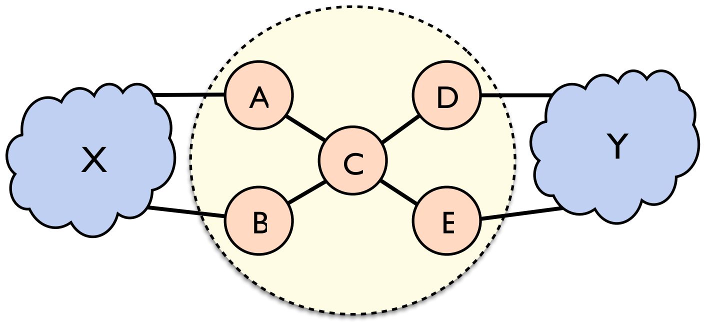


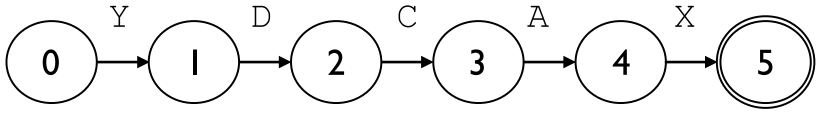


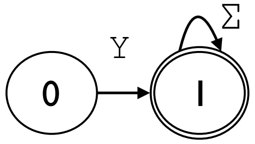


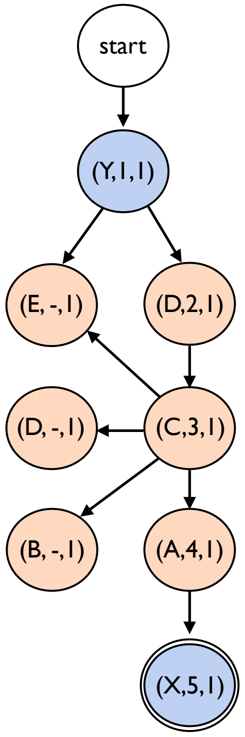


Constructing the Product Graph (PG)



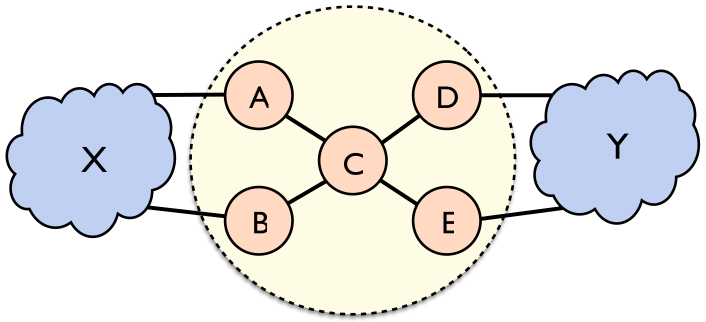


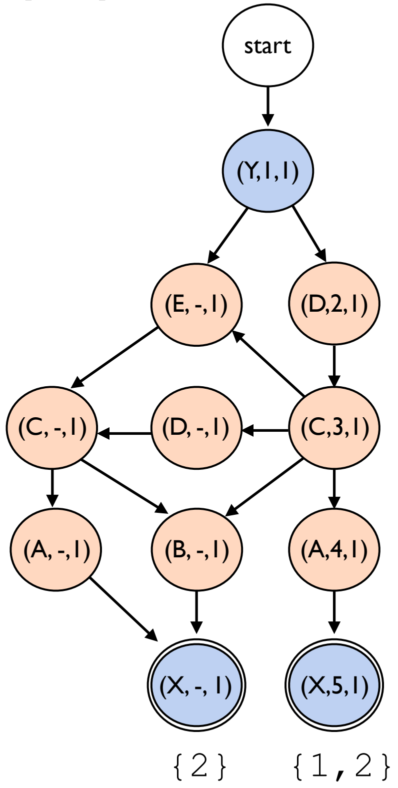


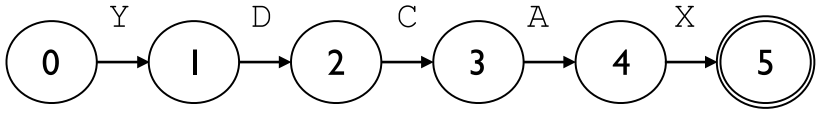


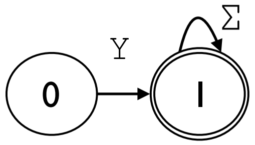
{1,2}

Constructing the Product Graph (PG)

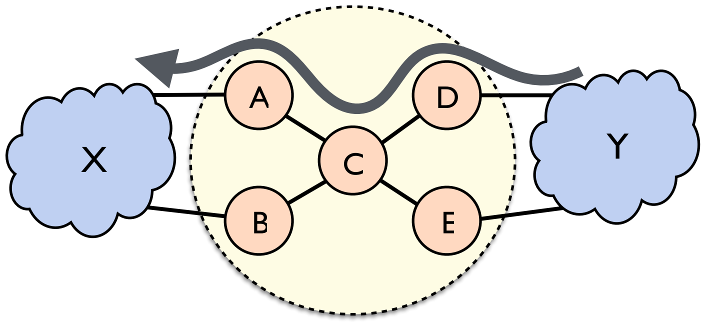


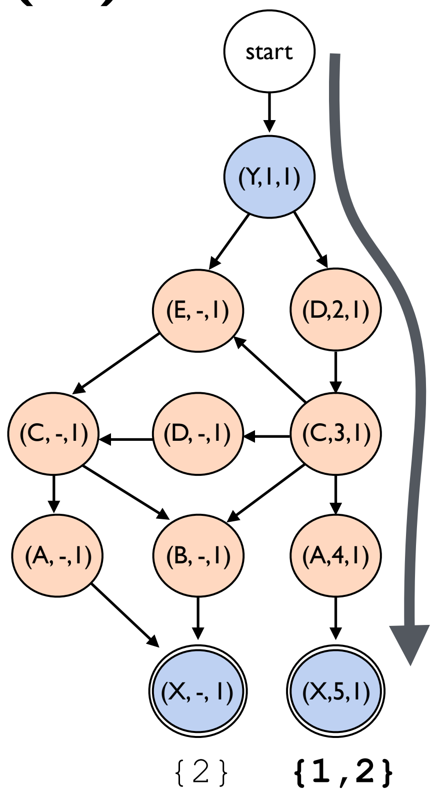


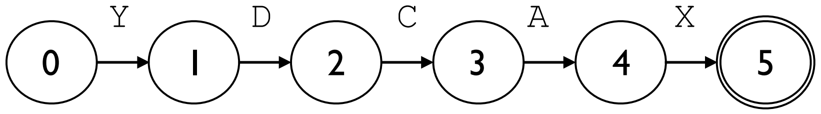


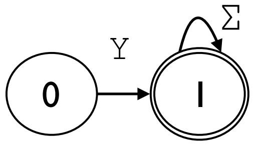


Constructing the Product Graph (PG)



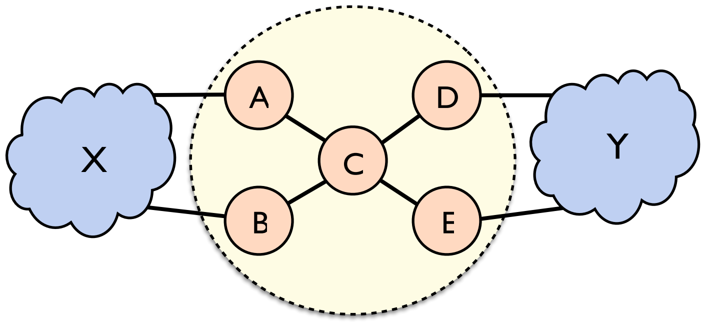


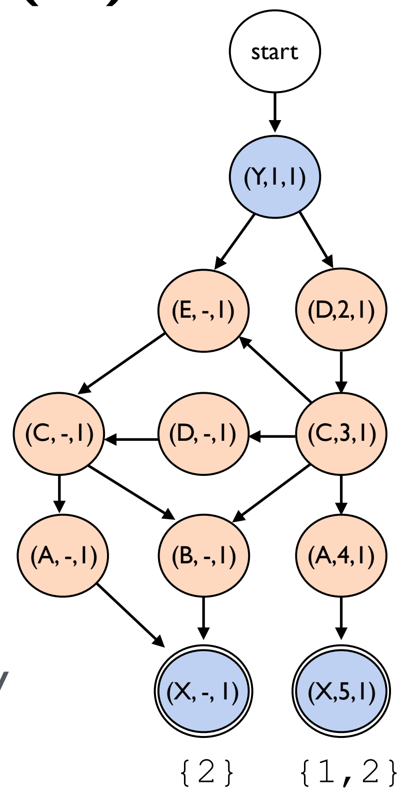




Accept: Y D C A X

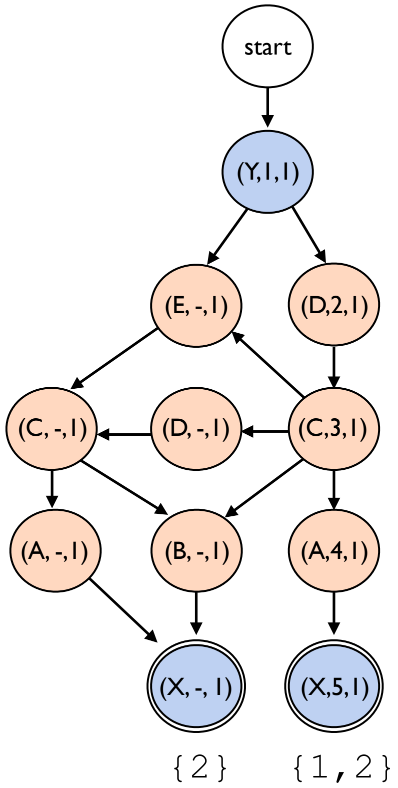
Constructing the Product Graph (PG)





Compact representation of all policy-compliant paths through the topology

Compilation to BGP:



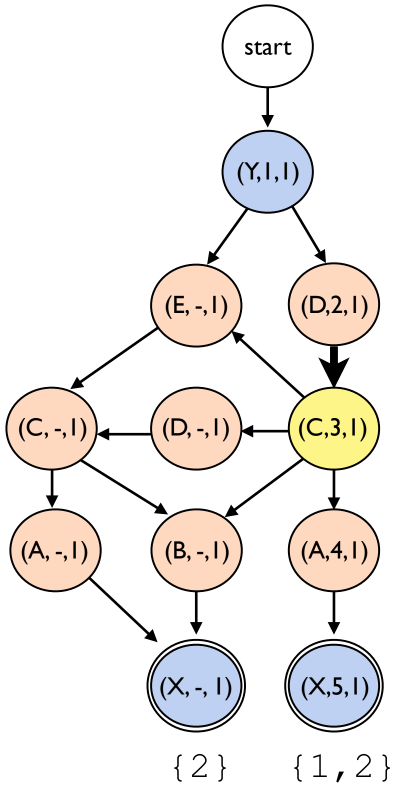
Idea 1: Restrict advertisements to PG edges

- Encode PG state in community tag
- Incoming edges — import filters
- Outgoing edges — export filters

↓

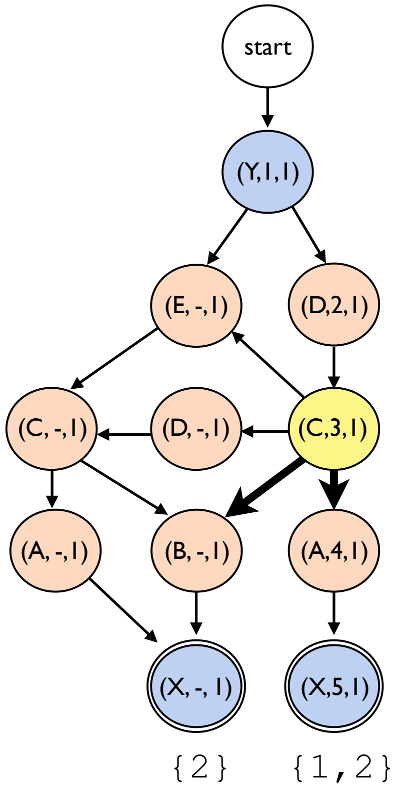
Let BGP find **some allowed** path dynamically

Compilation to BGP:



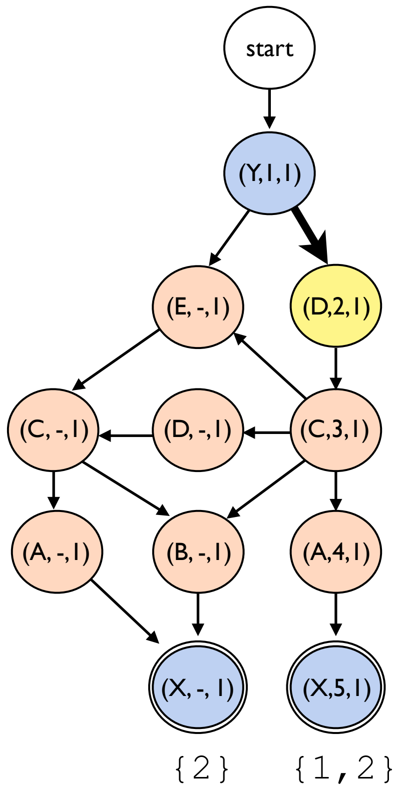
C allows import from D with tag (2,1)

Compilation to BGP:



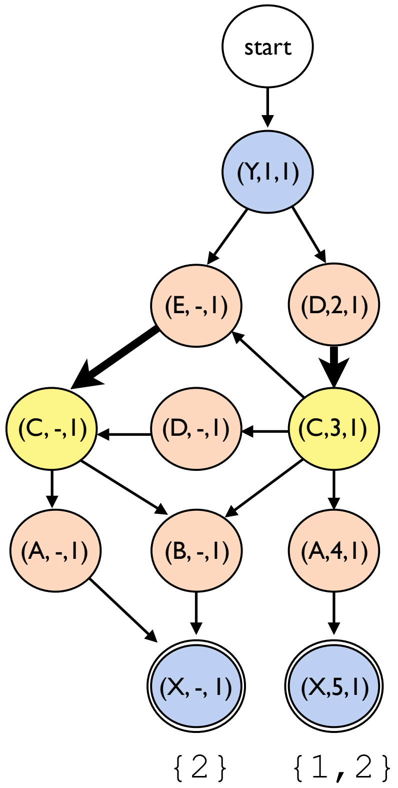
C exports to A,B with tag (3,1)

Compilation to BGP:



BGP regex filter: Y

Compilation to BGP:

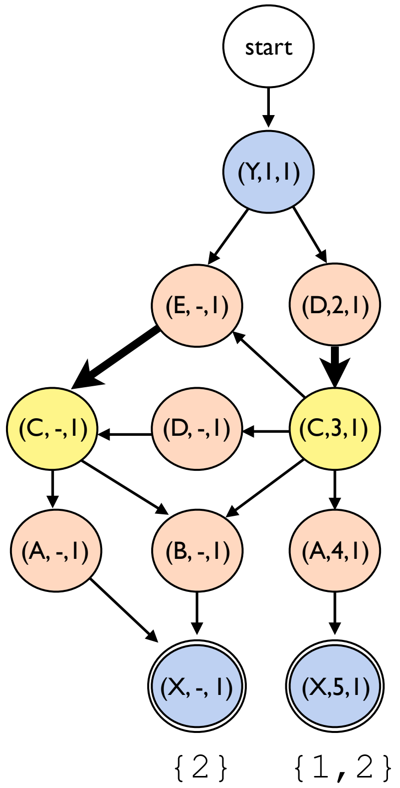


Idea 2: Find preferences

- Direct BGP towards best path
- Under all combinations of failures

Let BGP find **the best** path dynamically

Compilation to BGP:

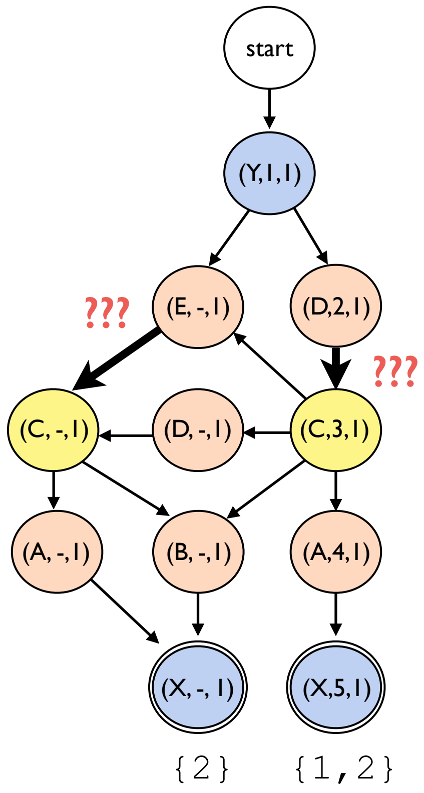


Router C

```
  match peer = D …

  match peer = E …
```

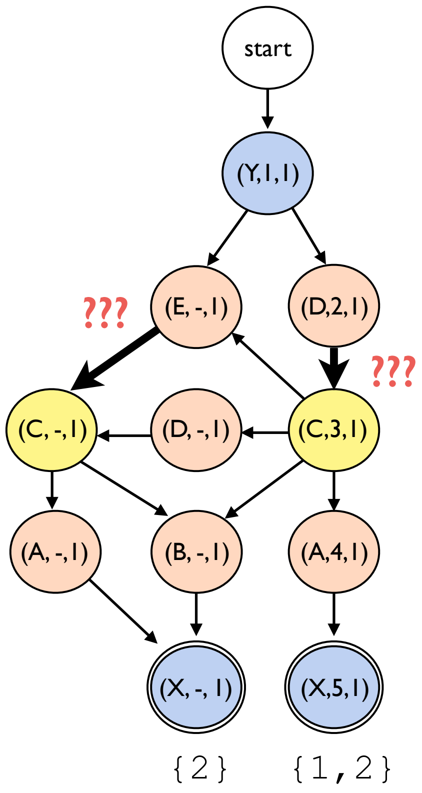
Compilation to BGP:



Router C

```
  match peer = D …
    local-pref ← ???
  match peer = E …
    local-pref ← ???
```

Compilation to BGP:

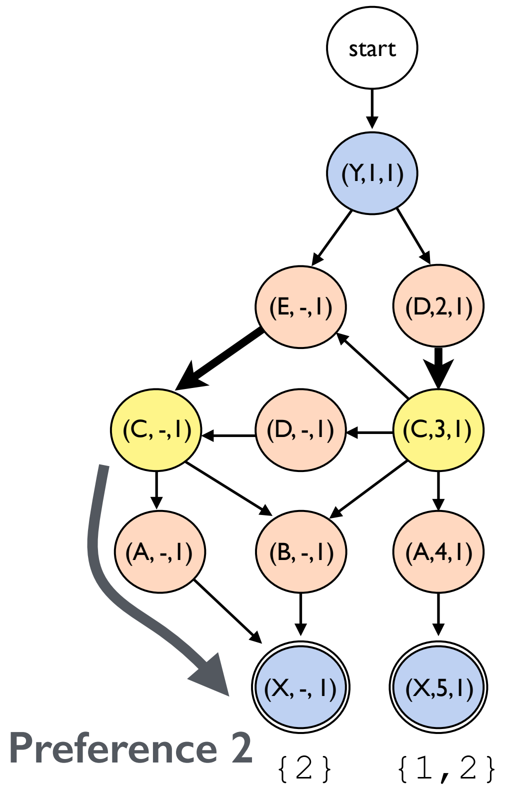


Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

Should we prefer messages from E over D?

Compilation to BGP:

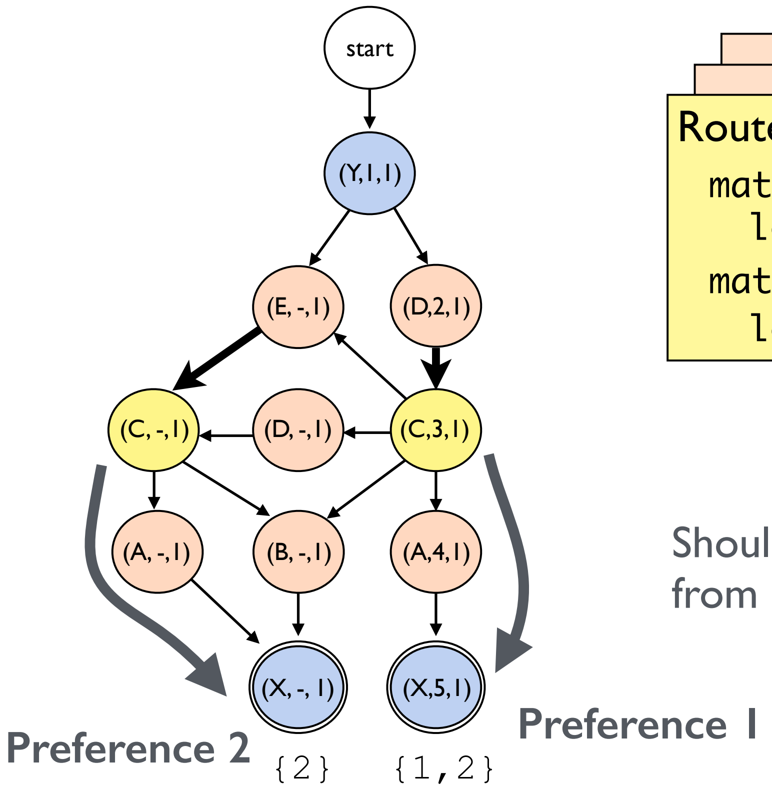


Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

Should we prefer messages from E over D?

Compilation to BGP:

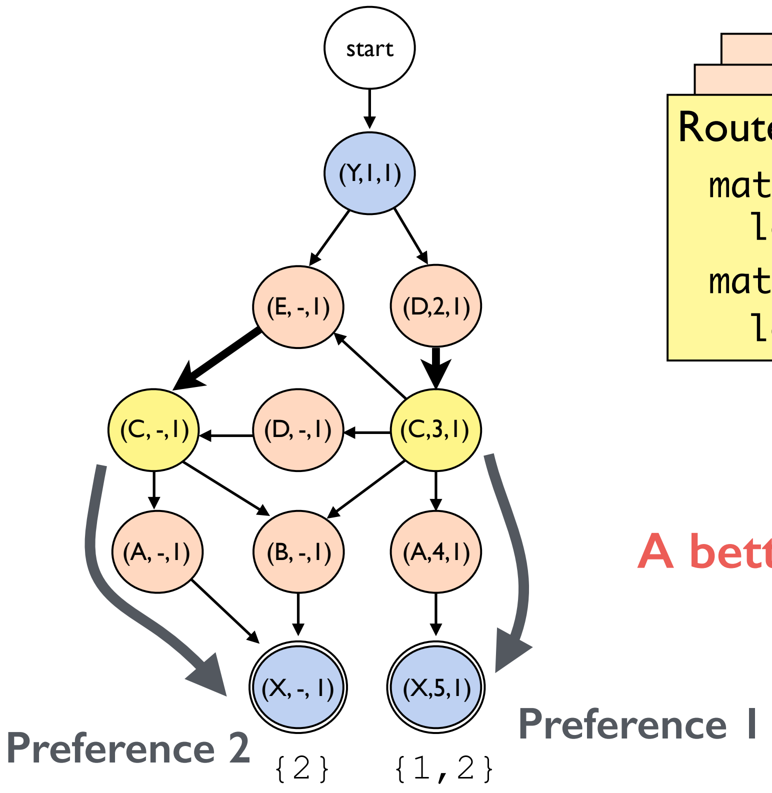


Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

Should we prefer messages from E over D?

Compilation to BGP:

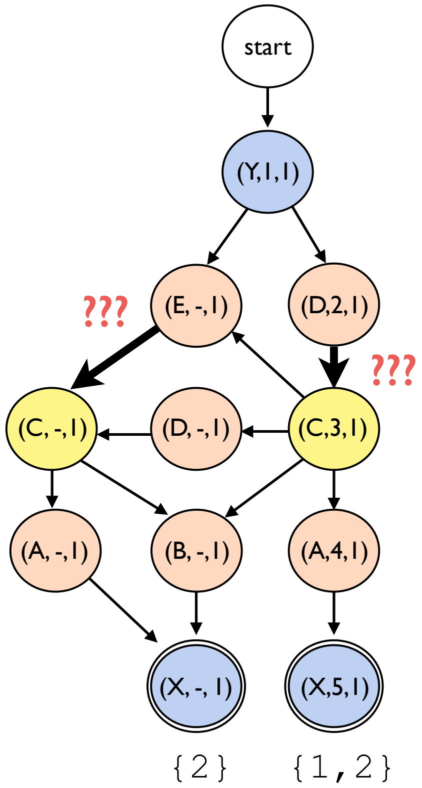


Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

A better path goes unused!

Compilation to BGP:

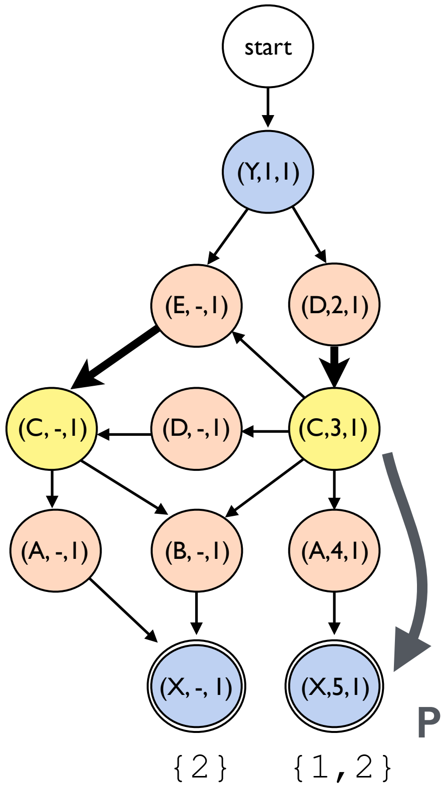


Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

What about preferring messages from D over E?

Compilation to BGP:



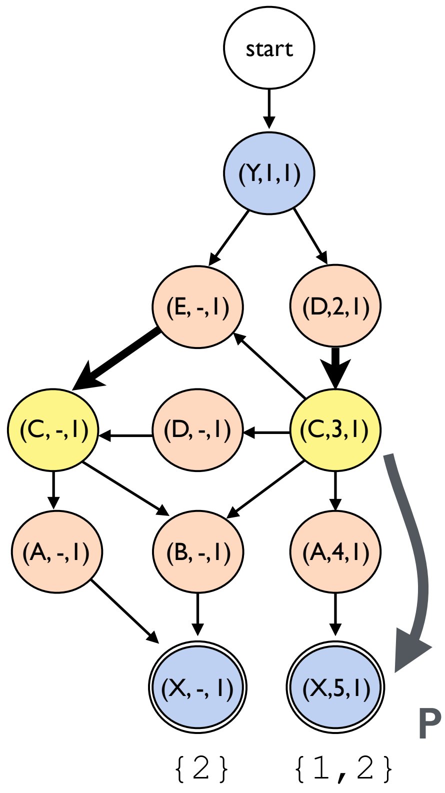
Preference 1

Router C

```
match peer = D …
   local-pref ← ???
match peer = E …
   local-pref ← ???
```

What about preferring messages from D over E?

Compilation to BGP:



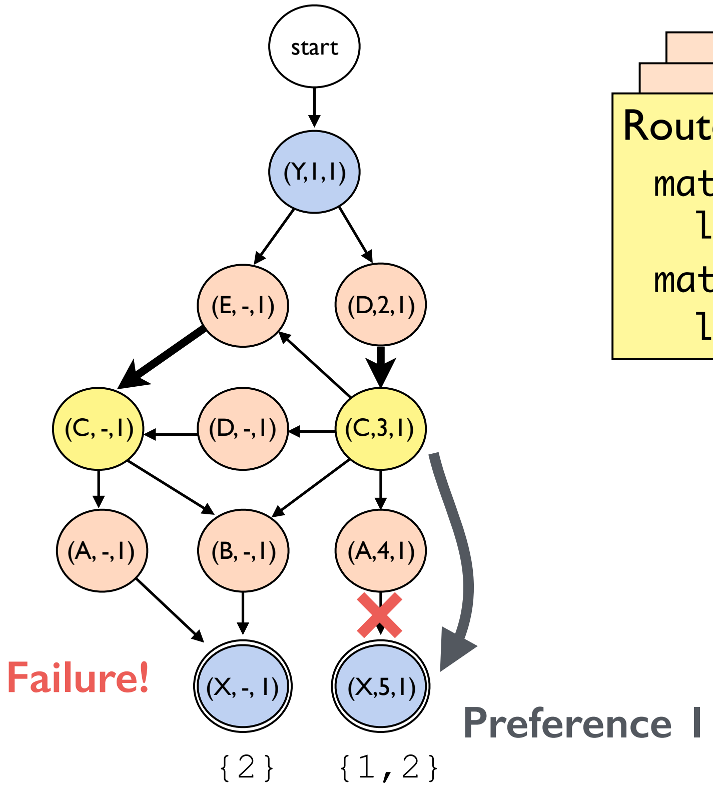
Preference 1

Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

No worse than preferring E

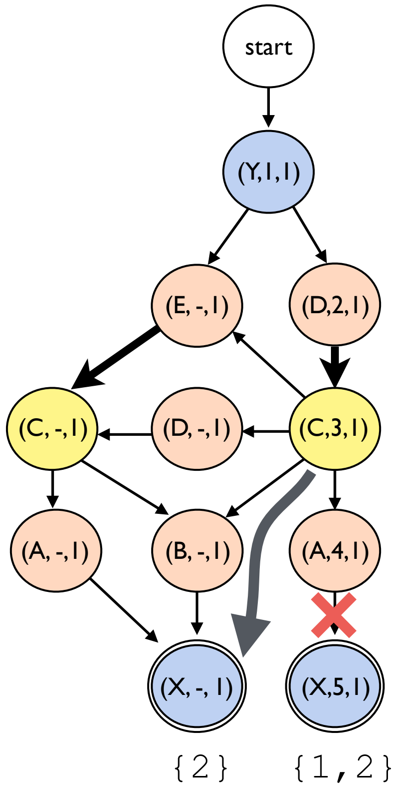
Compilation to BGP:



Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

Compilation to BGP:



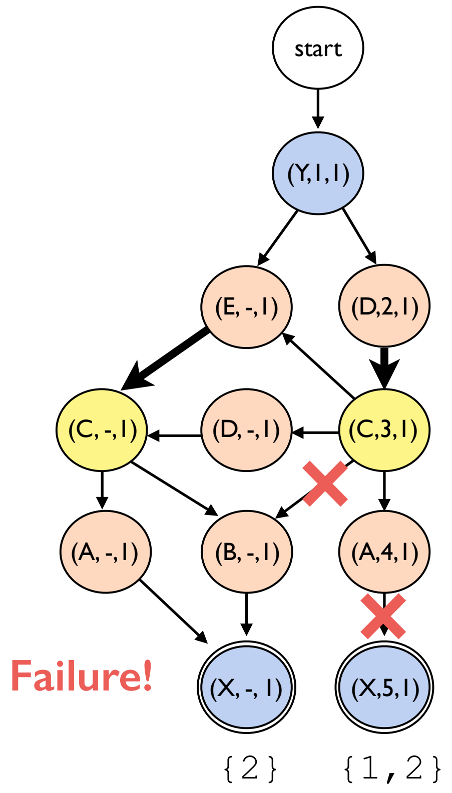
Preference 2

Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

No worse than preferring E

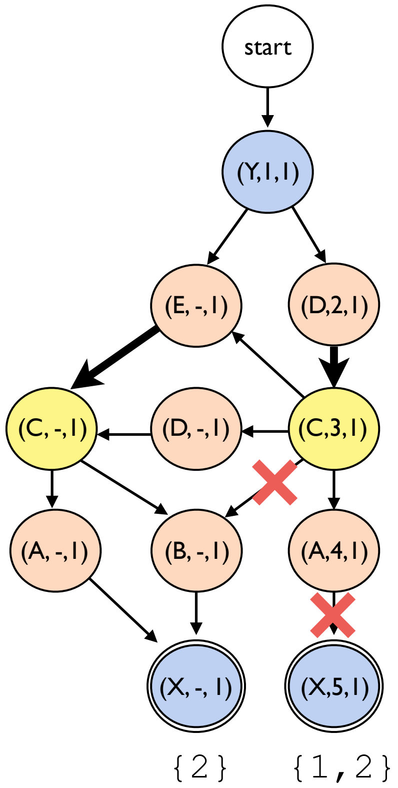
Compilation to BGP:



Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

Compilation to BGP:

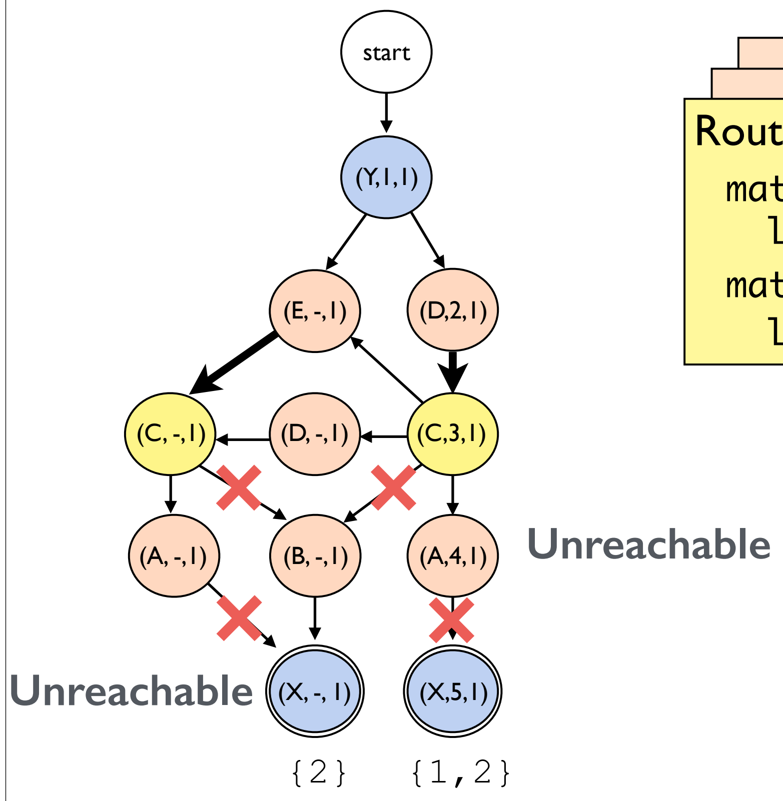


Unreachable

Router C

```
match peer = D …
   local-pref ← ???
match peer = E …
   local-pref ← ???
```

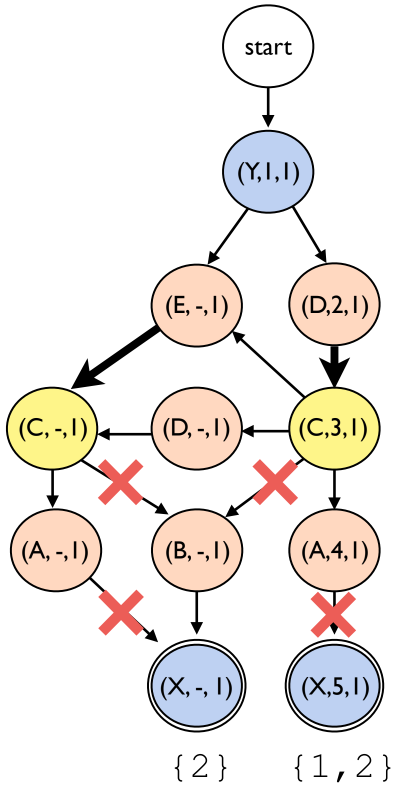
Compilation to BGP:



Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

Compilation to BGP:

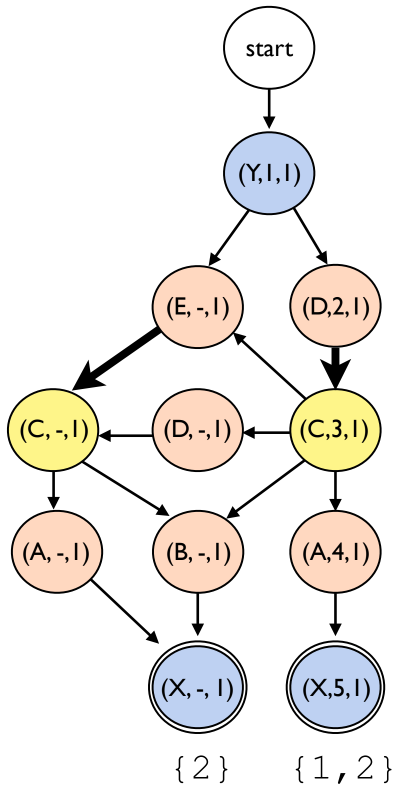


Router C

```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

No worse than preferring E

Compilation to BGP:



Router C

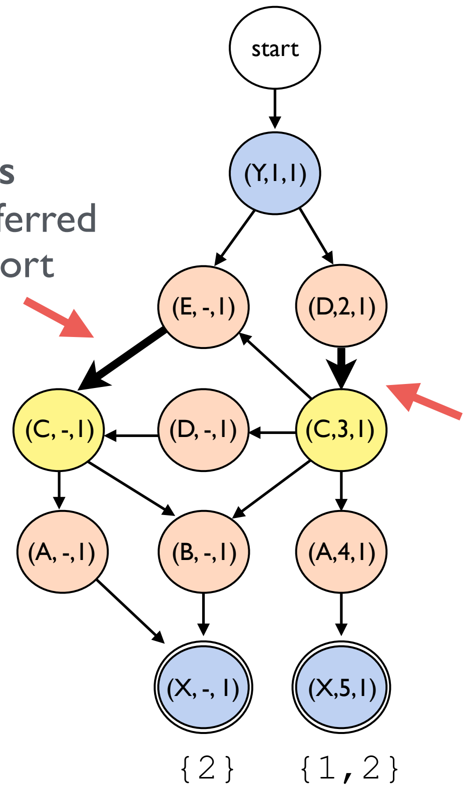
```
match peer = D …
  local-pref ← ???
match peer = E …
  local-pref ← ???
```

All failures checked efficiently by a greedy graph algorithm

See paper for details!

Compilation to BGP:

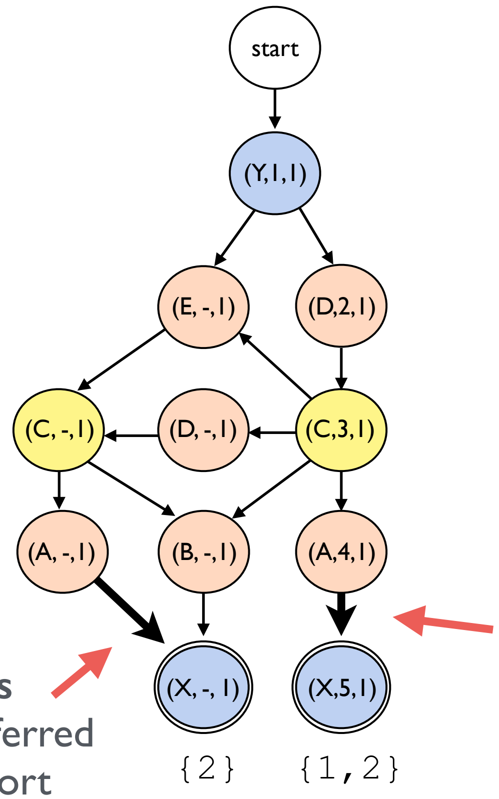
Less preferred import



Implementation: Local preference

More preferred import

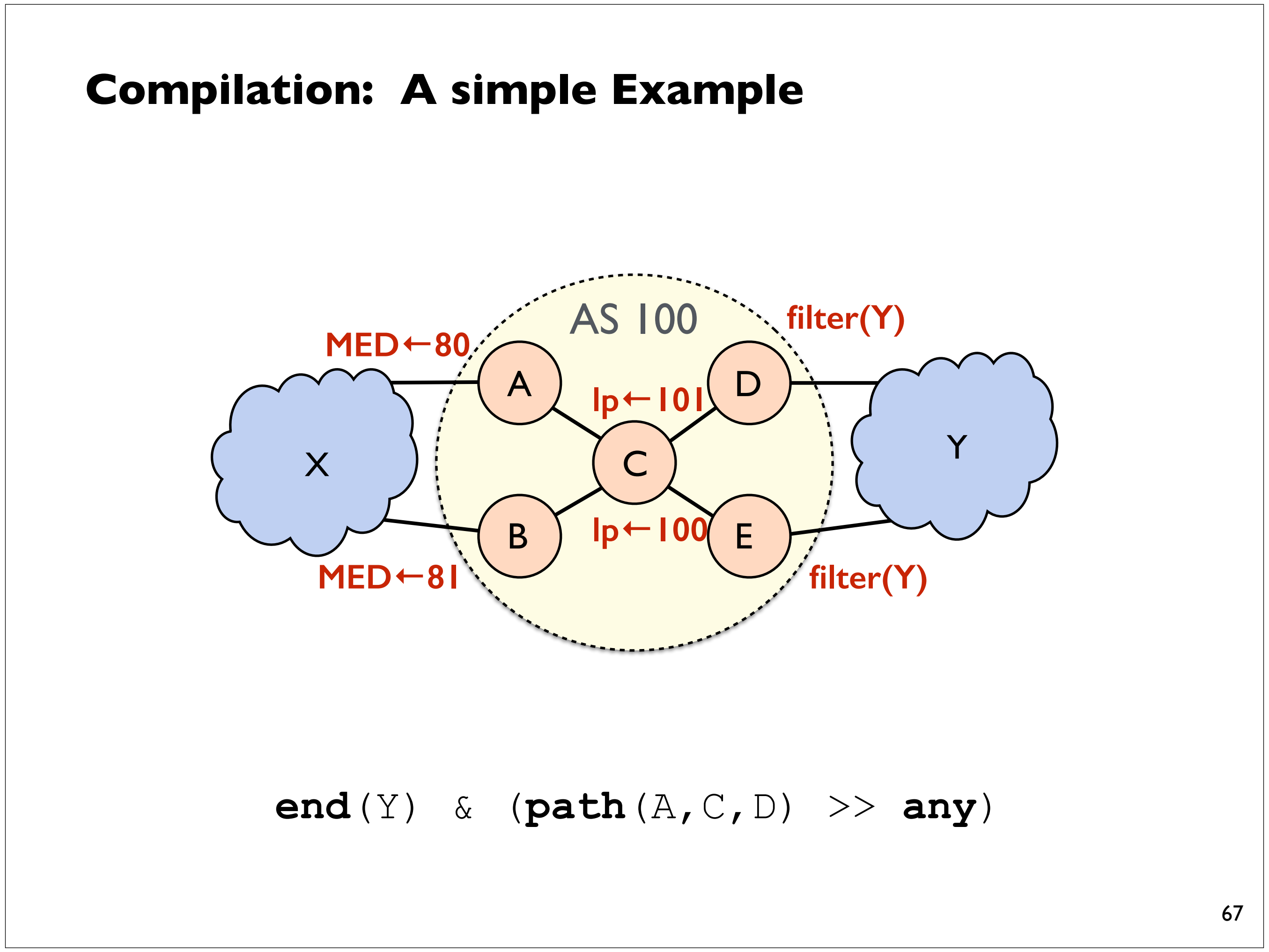
Compilation to BGP:



Implementation: MED/Prepending

More
preferred
import

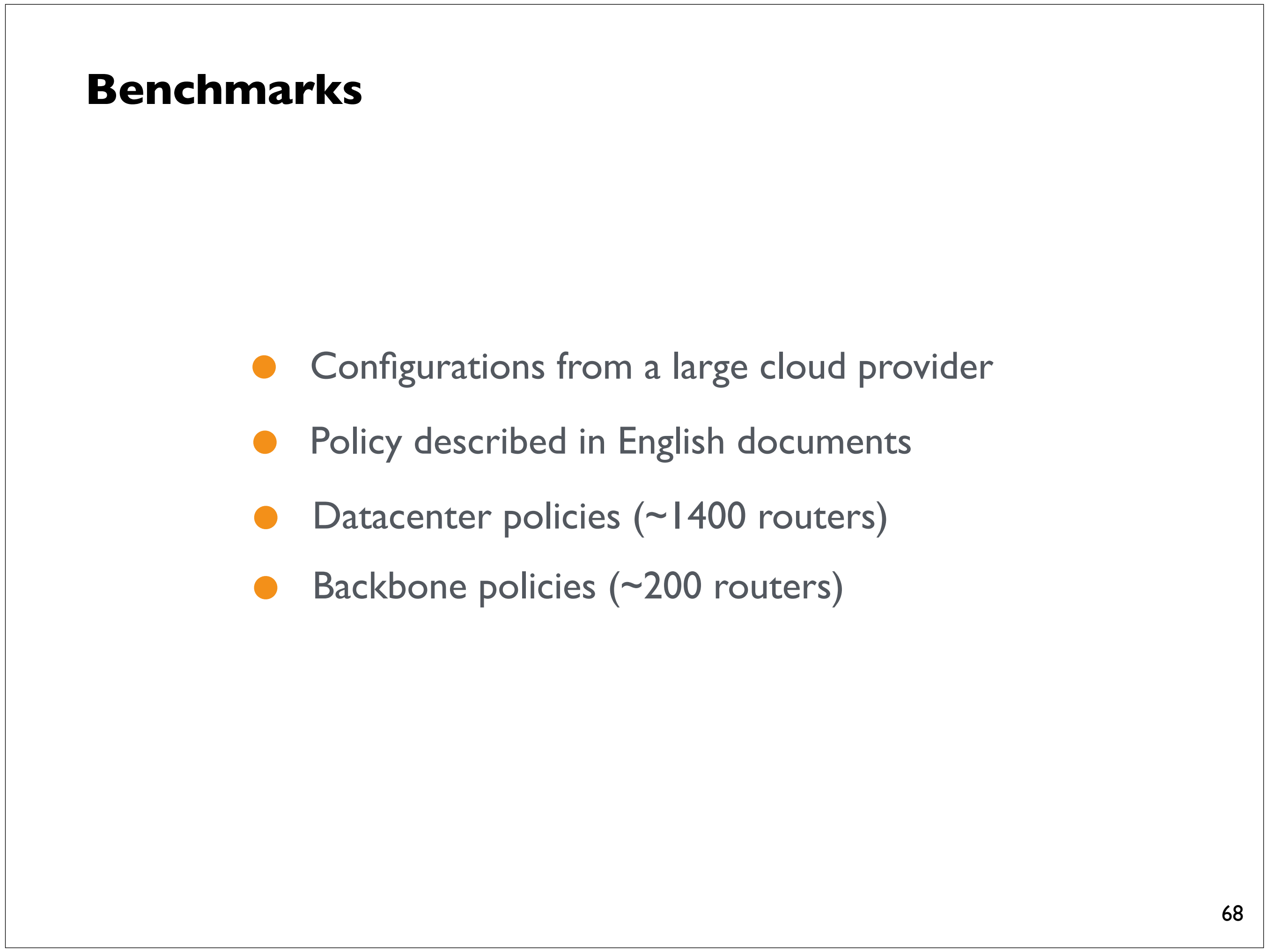
Less
preferred
import



Compilation: A simple Example

```
end(Y) & (path(A,C,D) >> any)
```

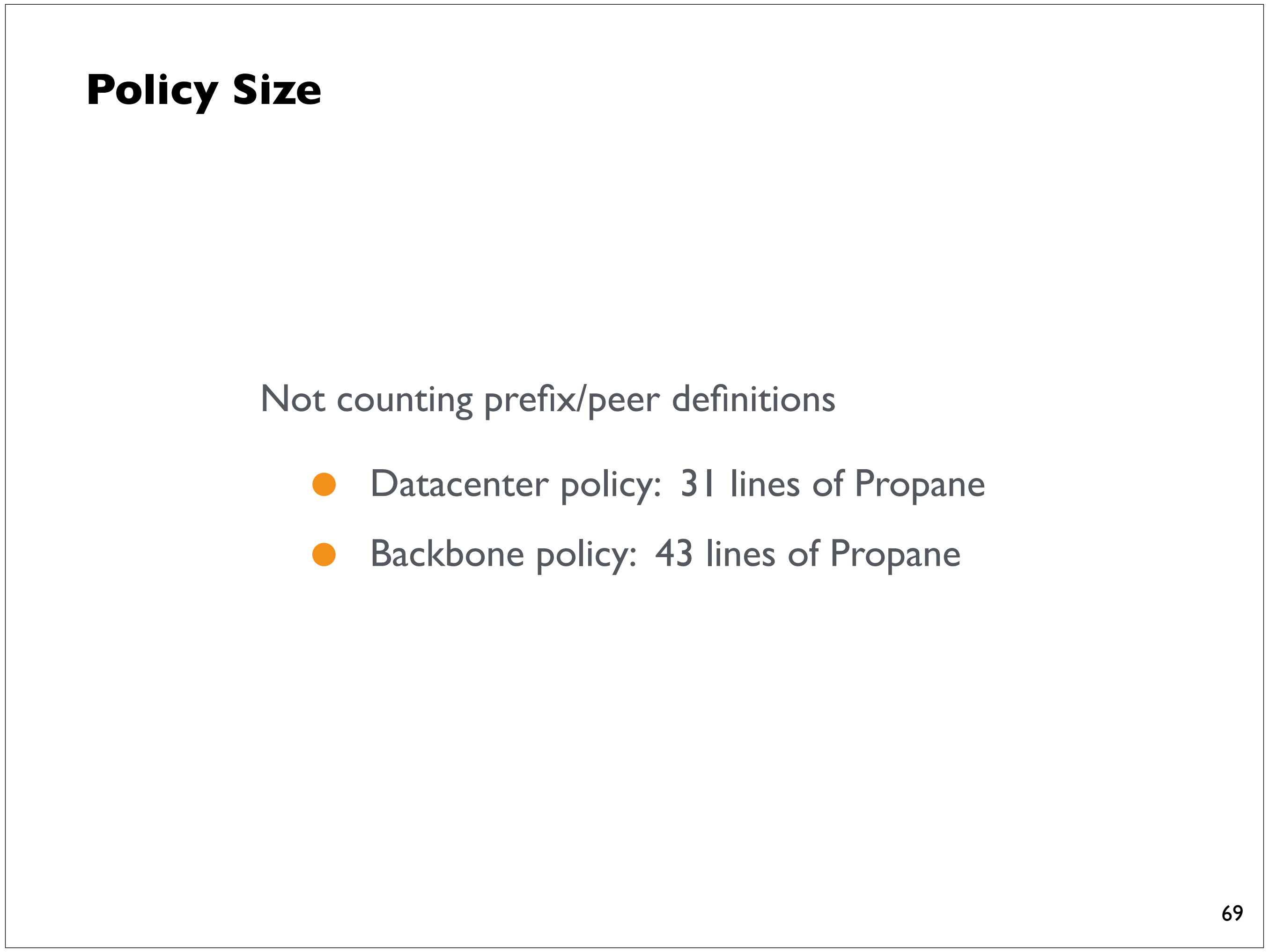
Mention demo & poster here (unless it is before, which I think it might be)



Benchmarks

- Configurations from a large cloud provider
- Policy described in English documents
- Datacenter policies (~1400 routers)
- Backbone policies (~200 routers)

We translated the documents into Propane



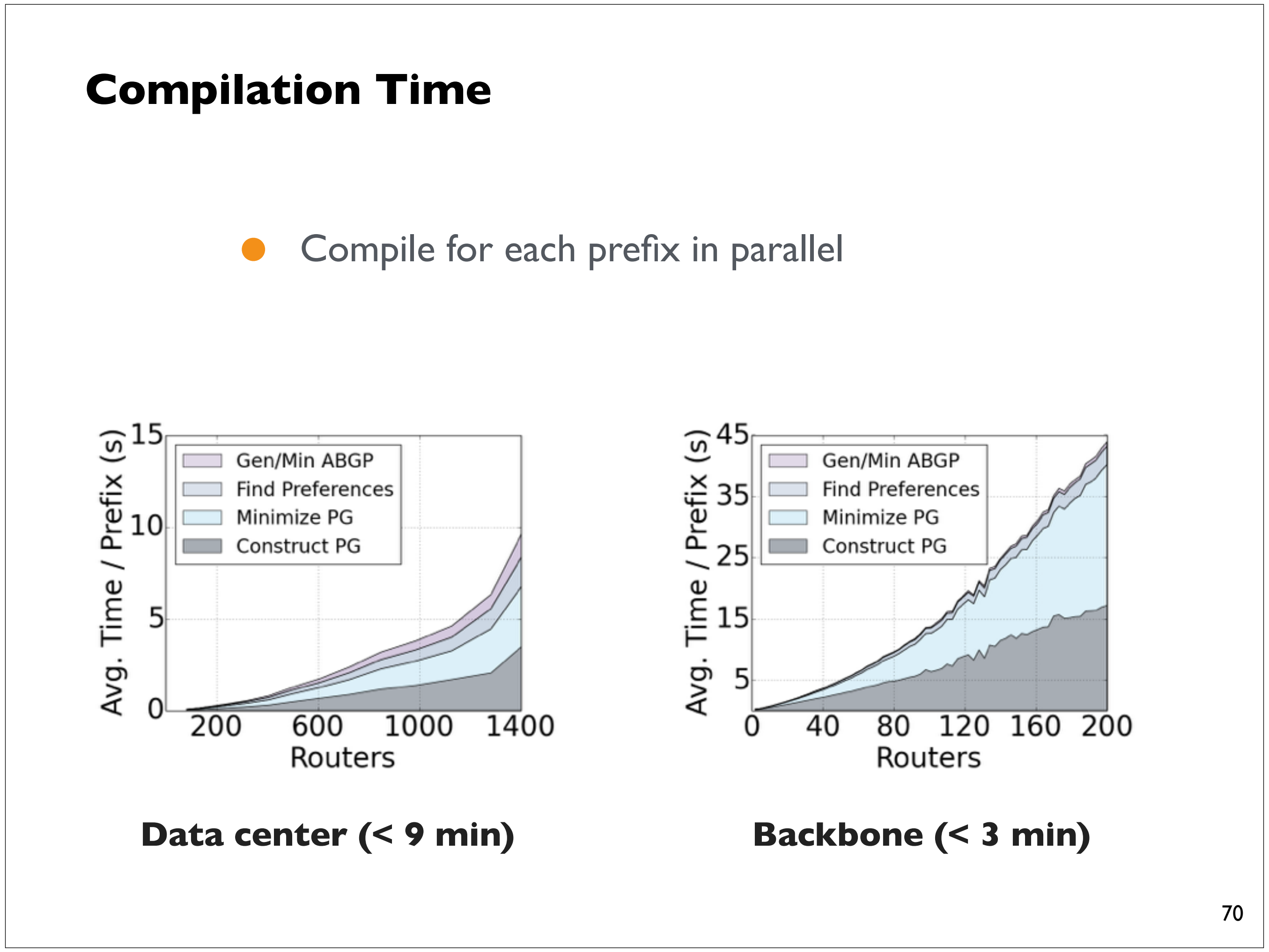
Policy Size

Not counting prefix/peer definitions

- Datacenter policy: 31 lines of Propane
- Backbone policy: 43 lines of Propane

Say something dramatic here (thousands of lines normally), orders of magnitude smaller

Biggest takeaway of the talk



Compilation Time

- Compile for each prefix in parallel

Data center (< 9 min)

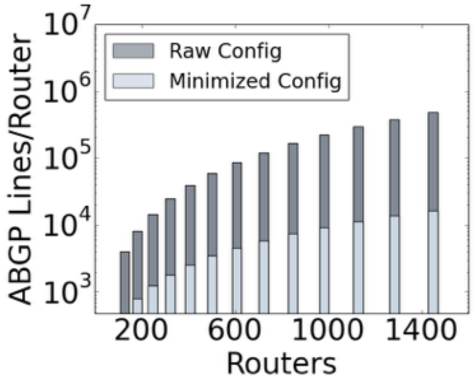
Backbone (< 3 min)

Say what the axes are

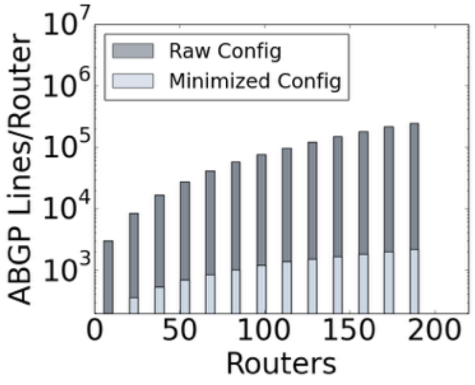
Say what the colors are (can read more about it in the paper)

Configuration Size

- Avoid using community tags when choices unambiguous
- Fall-through elimination of route maps

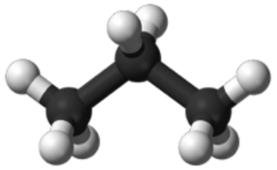


Data center



Backbone

Propane: Summary



High-level language

- Centralized network programmability
- Uniform abstractions for Inter- and Intra-domain routing
- Constraints specify preferred paths and backups in case of failure
- Core policy in 30-50 lines of Propane vs. 1000s

Compiler

- Distributed implementation via BGP
- Generates filters, preferences, community values, MEDs, etc.
- Static analysis guarantees policy compliance for all failures
- Scales to reasonably sized network topologies