Modeling the Complexity of Enterprise Routing Design

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The costs of complexity

- "We propose that this trend [towards more complex machines] is not always cost-effective, and may do more harm than good".
  - Patterson and Ditzel, "The Case for the RISC", 1980.

- "Complex architectures and designs have been (and continue to be) among the most significant and challenging barriers to building cost-effective large scale IP networks".
  - RFC 3439

Complex networks are hard to manage

```
class-map match-any QC2
  match access-group 102
  match access-group ACL2
class-map match-all QC3
  match dscp 5 7
class-map match-any CX
  ...
!
policy-map QP0
  class QC2
    bandwidth 100
    random-detect dscp-base
    random-detect dscp 10 40 60
    random-detect dscp 12 30 40
  class QC3
    bandwidth 50
    random-detect dscp-b
    random-detect dscp 5 20 3
    random-detect dscp 7 15
policy-map PX
  ......
!
```

```
interface Ethernet0/1
  service-policy input MarkingPolicy
!
interface ATM1/0.1 point-to-point
          cess-group 102 15 20 20 \
          et-dscp-transmit 10 \
          scp-transmit  12
          ss-group 103 2 4 4 \
          dscp-transmit 5 \
          dscp-transmit 7
          t QP0

          scp 10
          eg www

          1
          rce Loopback0
```

Over 80% of IT budget in enterprises
devoted to maintaining status quo
yet configuration errors account for
62% of network down time, and ..
enable 65% of cyber-attacks

   (Yankee Group, USITS 2003)

Could we quantify "complexity" ?

" When deciding between two approaches in networking, complexity is usual an important factor. However, the term 'complexity' is rarely well defined, and decisions on complexity are mostly made on subjective terms."

- IRTF Network Complexity Research Group Charter, 2011

What this paper is about...

- A first framework for quantifying complexity of enterprise routing designs

- Models that relate design to difficulty managing configurations
  - Facilitate design comparisons, what-if analysis

- Focus on Enterprise Routing Design
  - Critical, widely prevalent, time-consuming

Rest of the talk…

- Enterprise Routing Design
- Modeling design complexity
- Modeling details
- Validation
  - Longitudinal snapshots of Purdue's configurations
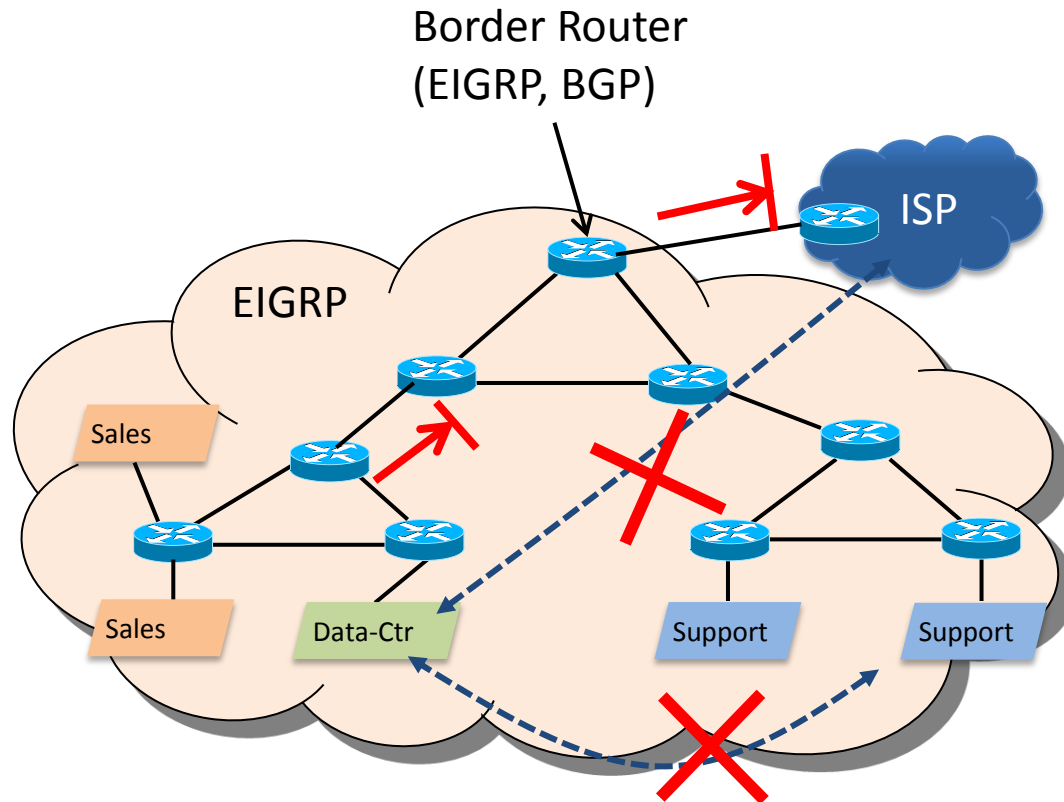
Routing Design Objectives
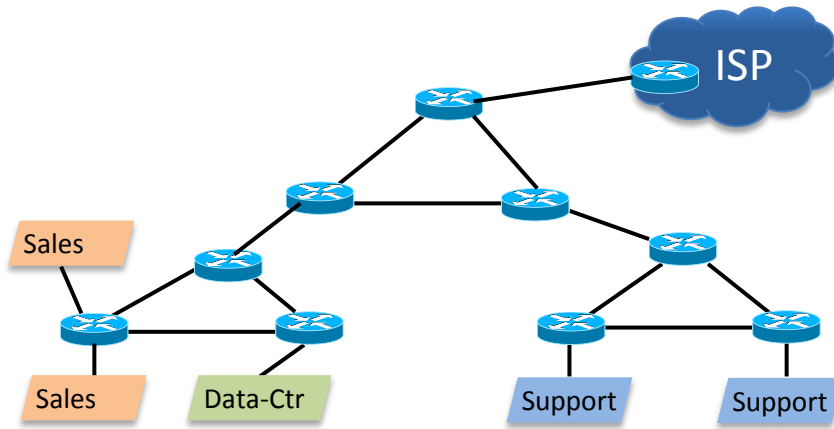
Policy Groups: Subnets with similar reachability policies [variant of IMC09]

	Data-Ctr
Sales	Y
Support	N
INT	N

Reachability Matrix

Other objectives: resiliency, traffic engineering etc.

Routing Design Primitives

Border Router
(EIGRP, BGP)

ISP

EIGRP

Sales

Sales

Data-Ctr

Support

Support

- Routing Instance [Maltz et al, Sigcomm 2004]
- Route Filters

Connecting Primitives
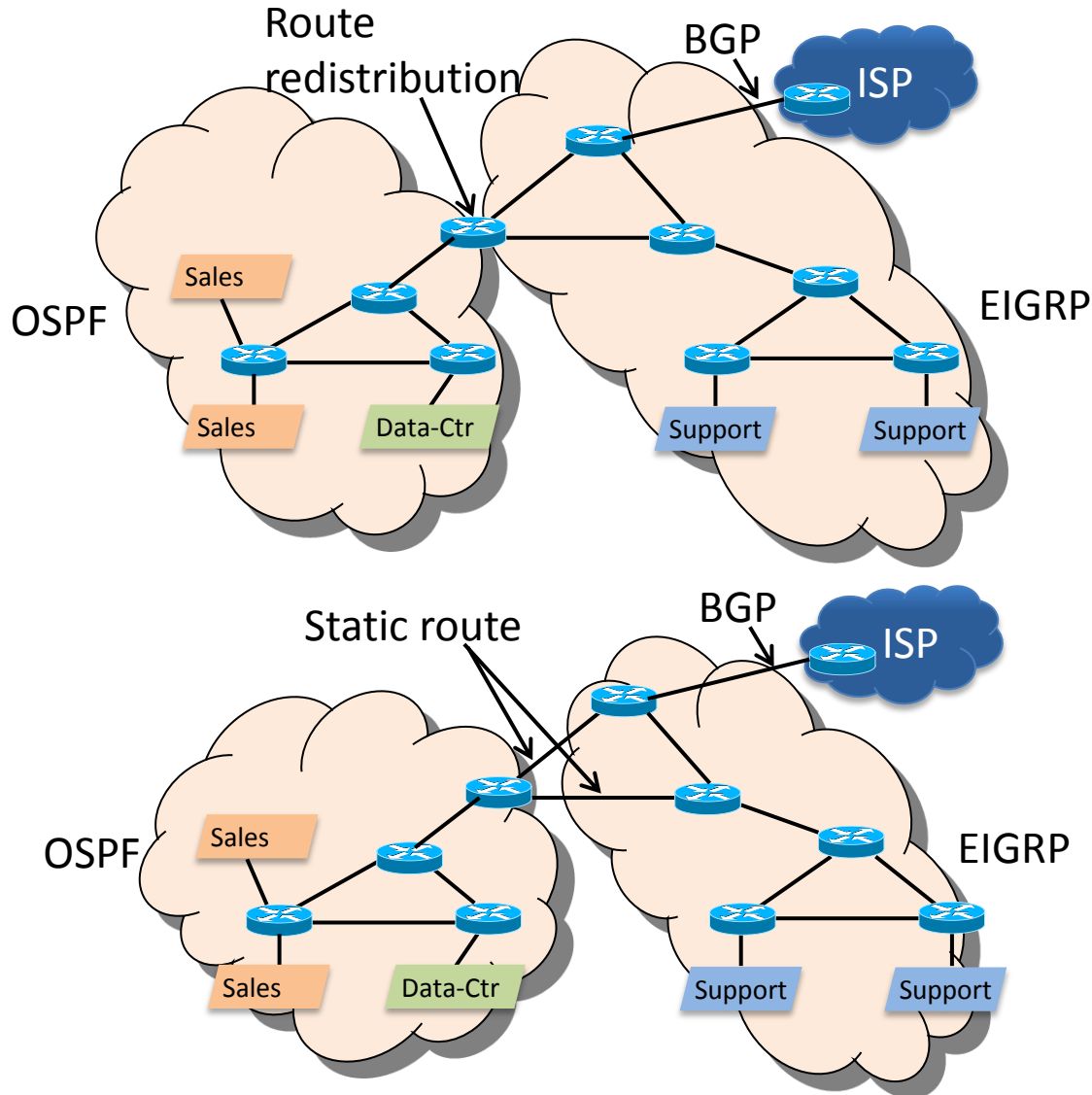
Choosing a Routing Design

- Many acceptable choices for operators:
  - Number of instances, mapping routers to instances, connecting primitives etc.
- Design complexity can provide guidance
  - Complexity: important, neglected, subjective
  - Complement performance metrics (e.g., # of hops)

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Prior efforts at quantifying complexity

- Protocol complexity [Chun et al, NSDI 08]
  - Based on state of distributed protocols
  - Dependencies leading to given state
  - E.g. Distance Vector Vs. Link State
- Configuration complexity [Benson et al, NSDI 09]
  - Family of metrics to capture complexity of network configurations
  - Correlation with difficulty managing networks established through operator interviews

Measuring Configuration Complexity

- Key metric: *# of configuration dependencies (referential Links)*

```
class-map match-any QC2
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class-map match-any CX
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  random-detect dscp 10 40 60 10
  random-detect dscp 12 30 40 10
 class QC3
  bandwidth 50
  random-detect dscp-based
  random-detect dscp 5 20 30 5
  random-detect dscp 7 15 20 5
policy-map PX
 ......
!
```

```
interface Ethernet0/1
 service-policy input MarkingPolicy
!
interface ATM1/0.1 point-to-point
 rate-limit output access-group 102 15 20 20 \
  conform-action set-dscp-transmit 10 \
  exceed-action set-dscp-transmit 12
 rate-limit output access-group 103 2 4 4 \
  conform-action set-dscp-transmit 5 \
  exceed-action set-dscp-transmit 7
 service-policy output QP0
!
access-list 102 permit ip any any dscp 10
access-list 102 permit tcp any any eq www
access-list 103 permit ip any any
ip access-list extended ACL2
   permit ip any any dscp 12
!
router bgp 1
 no synchronization
 neighbor 10.10.10.101 remote-as 1
 neighbor 10.10.10.101 update-source Loopback0
 no auto-summary
!
```
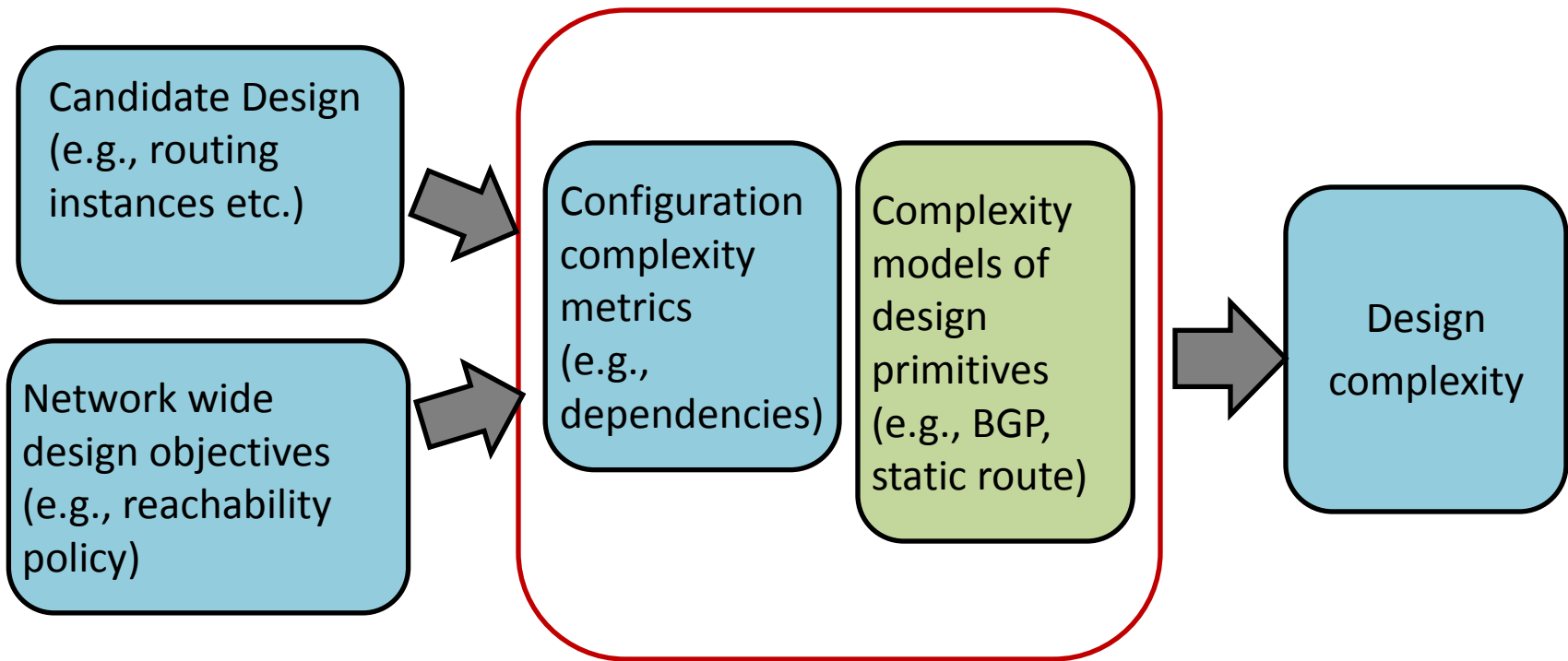
Challenge: Network Design Complexity

- Reason about "higher-level" network designs
  - Not just "lower-level" configurations
- Understand sources of complexity
  - E.g., misalignment of routing instances and reachability policies
- What-if Analysis
  - E.g., different set of routing instances ?
  - E.g., replacing static routes with BGP?
- Greenfield network design
  - No access to configuration files

Modeling design complexity

Candidate Design (e.g., routing instances etc.)

Network wide design objectives (e.g., reachability policy)

Configuration complexity metrics (e.g., dependencies)

Complexity models of design primitives (e.g., BGP, static route)

Design complexity

Facilitates green-field design, what-if analysis etc.

Rest of the talk…

- Enterprise Routing Design
- Modeling design complexity
- Modeling details
 - Intra-Instance complexity
  - Inter-Instance complexity
- Validation

Modeling Single Instance Complexity

- Key cause of complexity:
  - Multiple policy groups within an instance

Filter routing updates from s4,s5

Filter routing updates from s1,s2
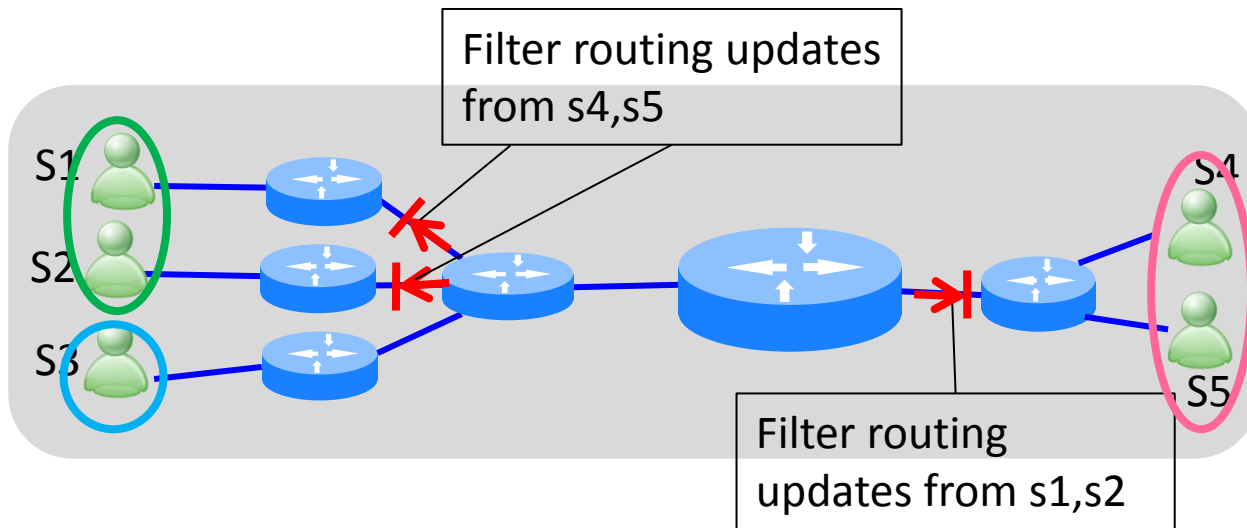
	s1	s2	s3	s4	s5
s1	-	Y	Y	N	N
s2	Y	-	Y	N	N
s3	Y	Y	-	Y	Y
s4	N	N	Y	-	Y
S5	N	N	Y	Y	-

Modeling Single Instance Complexity

	s1	s2	s3	s4	s5
s1	-	Y	Y	N	N
s2	Y	-	Y	N	N
s3	Y	Y	-	Y	Y
s4	N	N	Y	-	Y
S5	N	N	Y	Y	-

# of filters
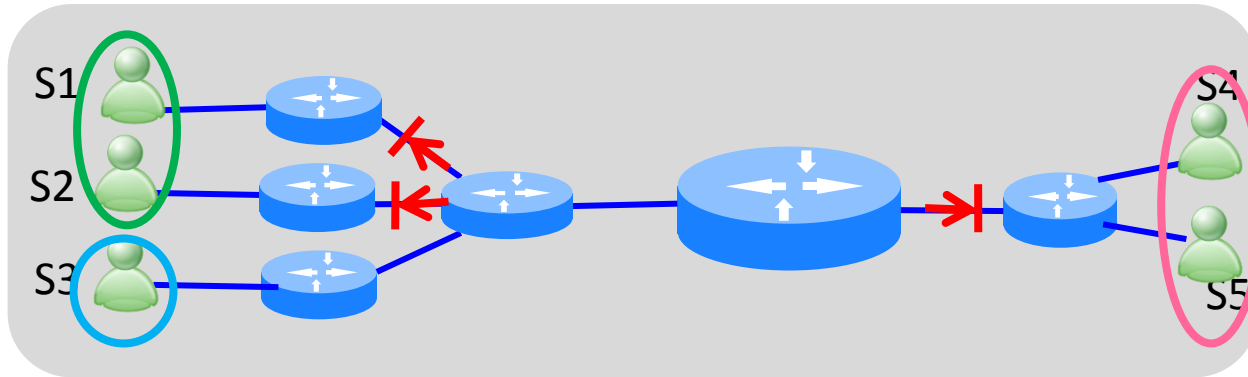
Filter configuration complexity

- Complexity depends on:
  - Number of policy groups
  - Topology (# of paths between policy groups, edge-cut sets)
  - # of subnets that must be filtered between policy group pairs
- Estimation details described in paper.
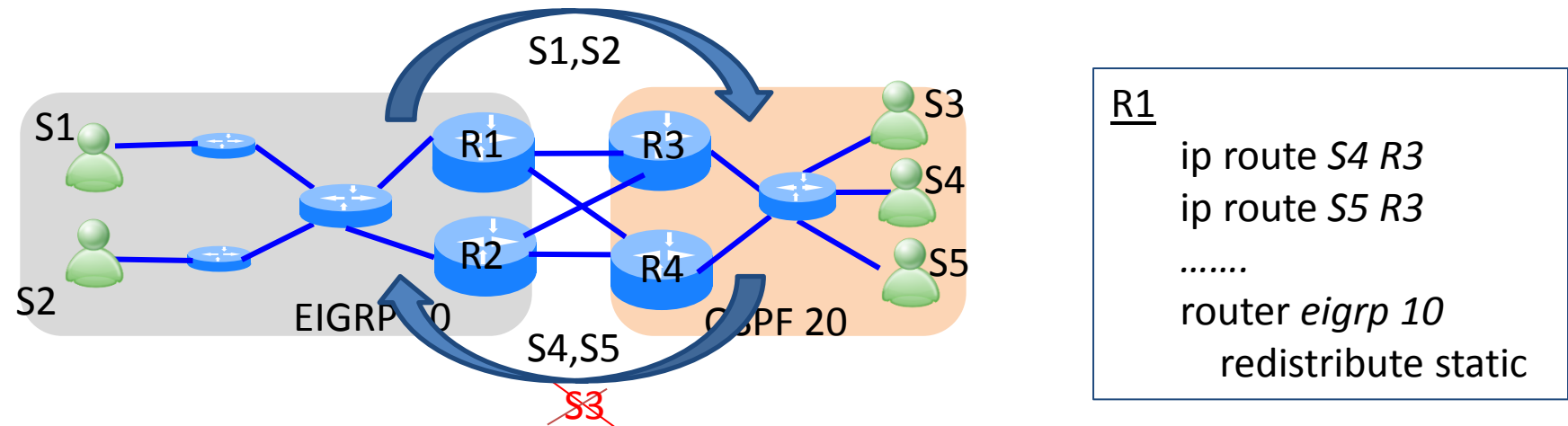
Modeling Inter Instance Complexity
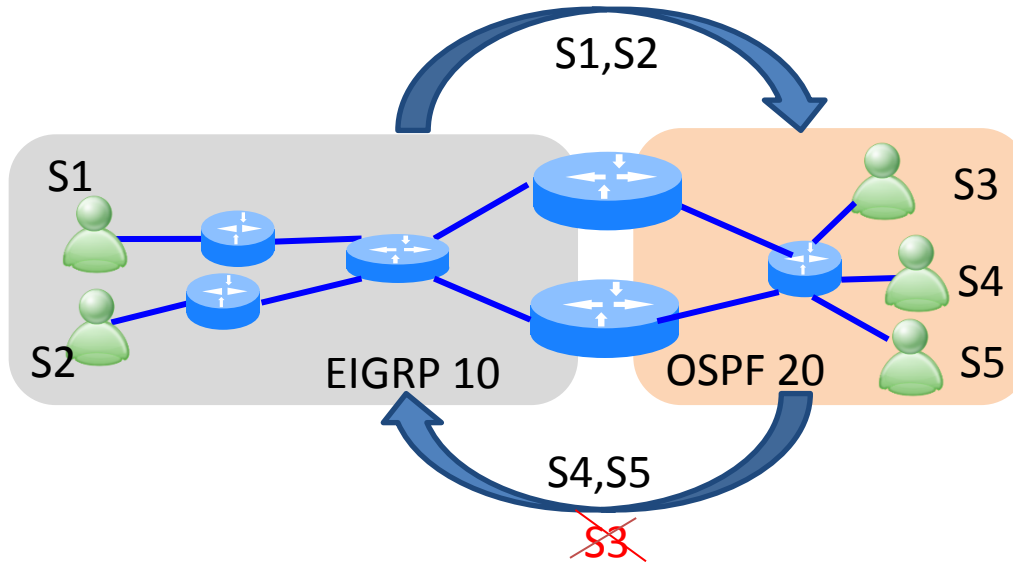
Sources of Complexity: Propagation of routes across instances while meeting
- Reachability requirement
- Resiliency requirement

Different connecting primitives may lead to different complexity
- Route Redistribution
- Static Routes
- BGP

Modeling Static Routes


```
R1
    ip route S4 R3
    ip route S5 R3
    .......
    router eigrp 10
        redistribute static
```

- Key issue: Failure handling.
  - Configuration for automatic re-routing on failures
- Complexity depends on
  - # of border routers, # of arcs across instances
  - # of propagated routes
    - Basic Propagation, Failure handling

Modeling Route Redistribution
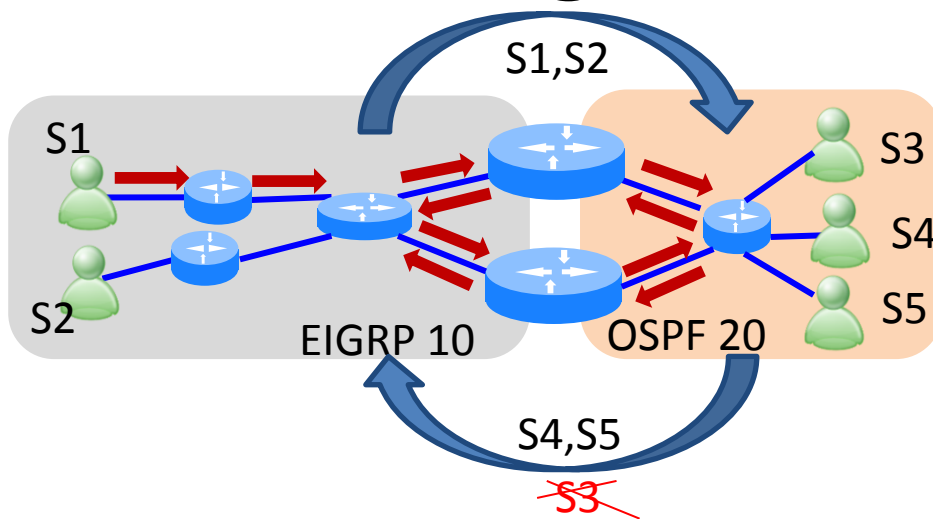
- Key Issue: Preventing Route Feedback
  - Route filters, tags
- Complexity depends on
  - # of border routers
  - # of propagated routes
    - Basic propagation, feedback prevention
  - Fraction of routes propagated

Which primitive lowers complexity?

- Depends on several factors
  - # of border routers
  - # of propagated routes
  - Fraction of routes propagated
- Static Route:
  - Single Border Router, small # of routes
- Route Redistribution
  - Single Border Router, lots of routes, most propagated.
- BGP
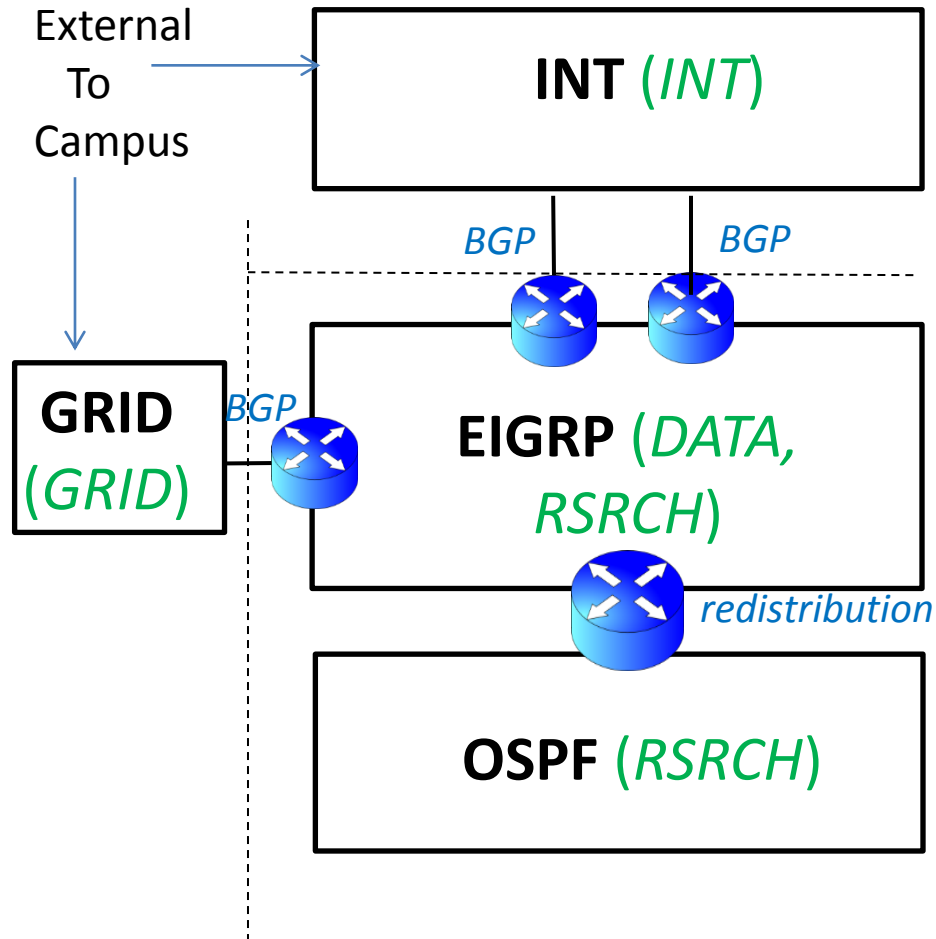 - Multiple Border Routers, most routes propagated

Rest of the talk…

- Enterprise Routing Design
- Modeling design complexity
- Modeling details
- Validation

Evaluation Study Overview

- Data-set
  - Longitudinal configuration snapshots of Purdue
    - 2009 – 2011
    - Major redesign in 2010
  - Physical topology data from CDP
  - ~100 routers, 1000 switches, 700 subnets
- Key Questions
  - Do our models match configuration-based metrics?
    - Yes, see paper
  - Feasible to lower complexity of operational designs?
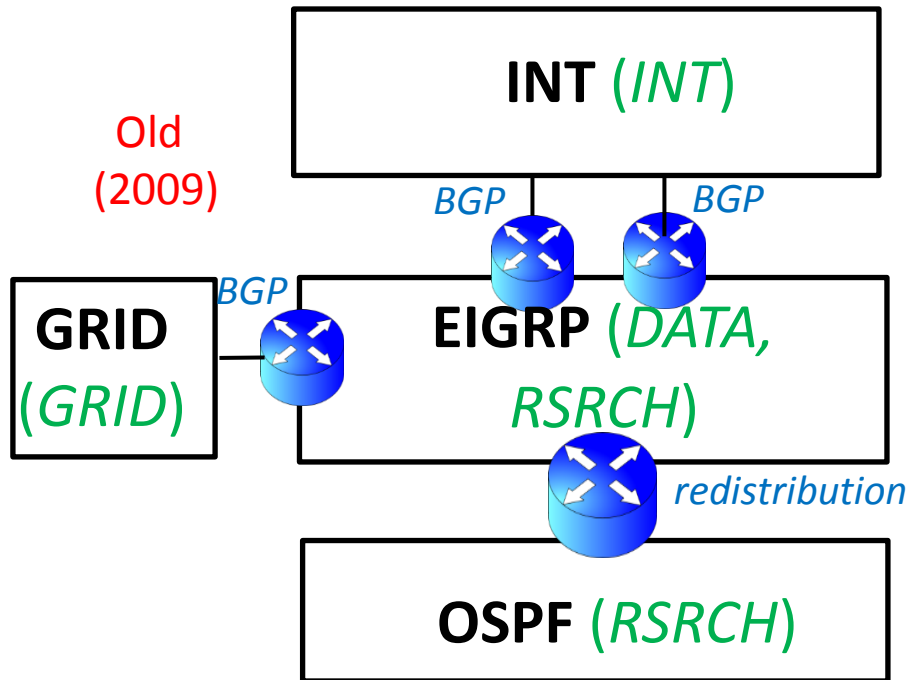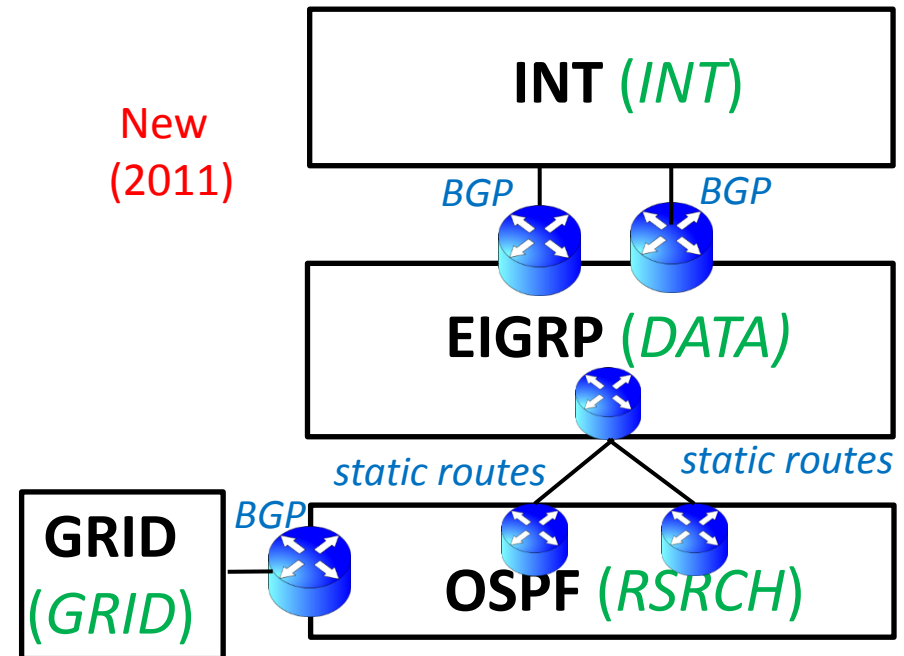
Purdue Campus Design (2009)

External To Campus

INT (*INT*)

BGP   BGP

BGP

GRID (*GRID*)

EIGRP (*DATA, RSRCH*)

redistribution

OSPF (*RSRCH*)

Reachability matrix

	DATA	RSRCH	GRID	INT
DATA	-	Partial	✕	all
RSRCH	all	-	all	all
GRID	✕	Partial	-	✕
INT	Partial	Partial	✕	-

Case Study of a Redesign

Old (2009)

INT (*INT*)

BGP   *BGP*

BGP

GRID (*GRID*)

EIGRP (*DATA, RSRCH*)

redistribution

OSPF (*RSRCH*)

New (2011)

INT (*INT*)

BGP   *BGP*

EIGRP (*DATA*)

static routes   *static routes*

GRID (*GRID*)

BGP

OSPF (*RSRCH*)

	EIGRP	OSPF	GRID	INT
EIGRP	Δ=-7	Δ=29	Δ=-1	Δ=0
OSPF	Δ=1	Δ=0	Δ=1	-
GRID	Δ=-6	Δ=6	-	-
INT	Δ=0	-	-	-

Δ: new - old

Are There Better Alternatives?

EIGRP (*DATA, RSRCH*)

redistribution

OSPF (*RSRCH*)

Old

EIGRP (*DATA*)

static routes

OSPF (*RSRCH*)

New

EIGRP (*DATA, RSRCH*)

static routes

OSPF (*RSRCH*)

Alternate Design HD-1

EIGRP (*DATA*)

redistribution

OSPF (*RSRCH*)
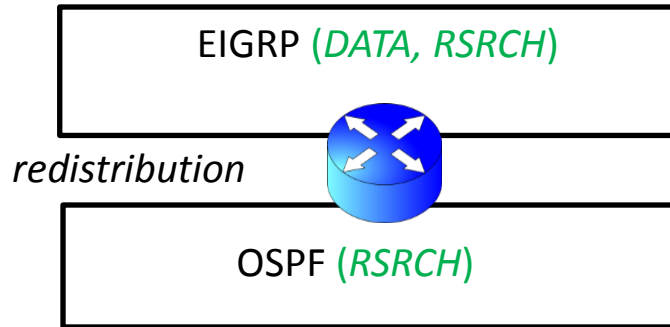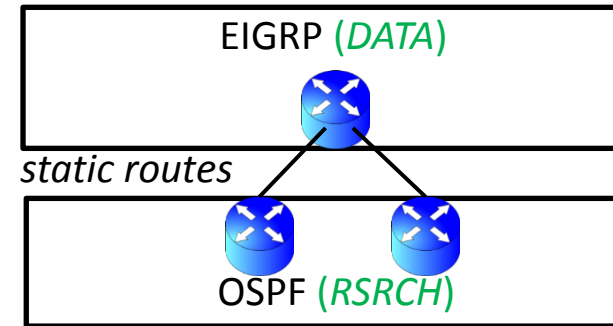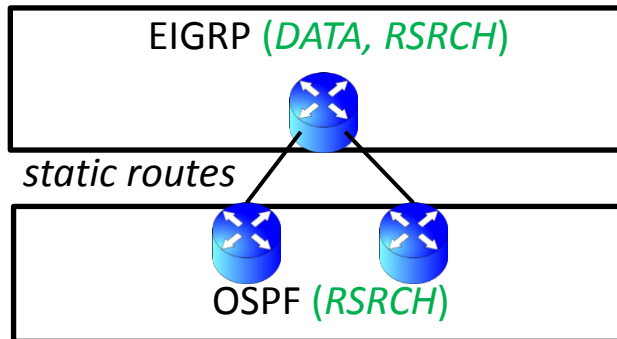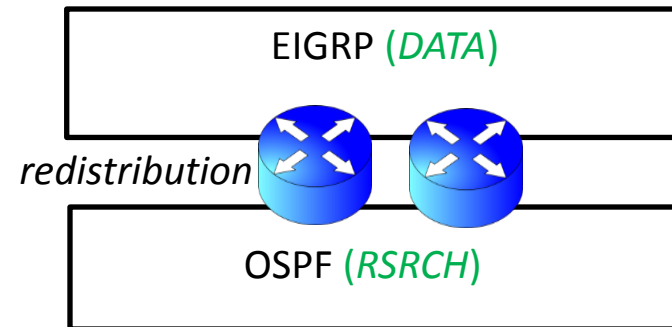
Alternate Design HD-2

Are There Better Alternatives?

EIGRP (*DATA*)

static routes   New

OSPF (*RSRCH*)

EIGRP (*DATA*)

redistribution   HD-2

OSPF (*RSRCH*)

Complexity (% of old)

250%

200%

150%

100%

50%

0%

new   HD-1   HD-2

HD-2 significantly lowers complexity
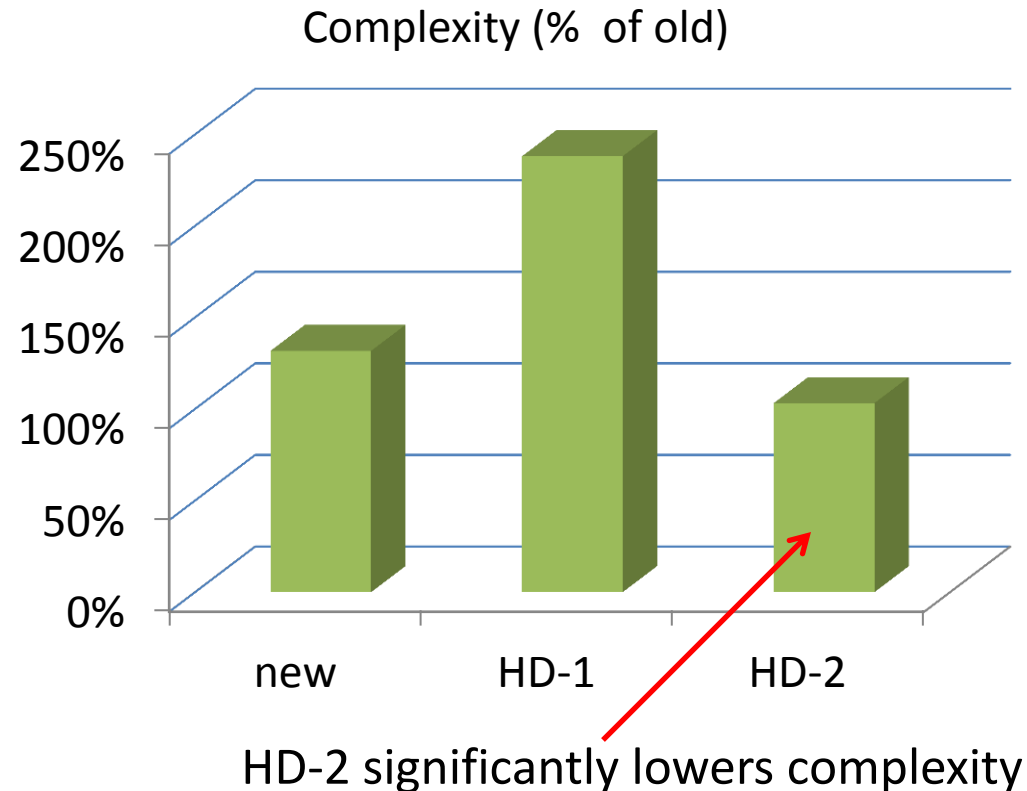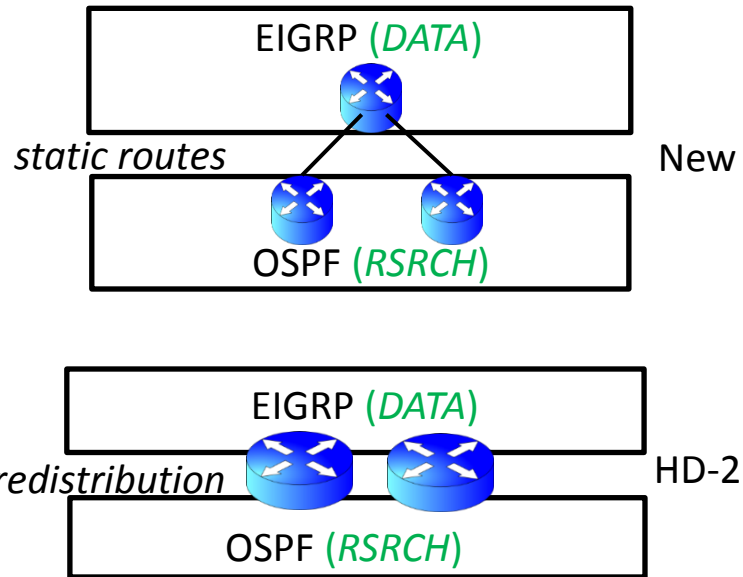
• Operators confirmed HD-1 would have been the ideal choice
  • However, operator group with diverse skill sets
  • Preferred static routes since less "knowledge" required for students

Conclusions

- Show it is feasible to
  - Quantify complexity of enterprise routing designs
- Distinguishing Aspect:
  - Design Complexity [Vs. Protocol/Configuration]
  - Enables what-if analysis, green-field designs etc.
- Substantial opportunity to lower complexity in an operational network
- Future work: Other design tasks, more complexity metrics, larger-scale validations