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On the Accurate Detection of Network Service Dependencies In Distributed Systems

(To appear in USENIX LISA 2012)

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Written Qualifying Examination

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Agenda

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- Introduction
- Motivation
- Related Work
- Our Contributions
  - Logarithm-Based Ranking
  - Service Inference
  - Detection of Network Service Clusters
- Experimental Evaluation
- Conclusion and Future Work

Introduction

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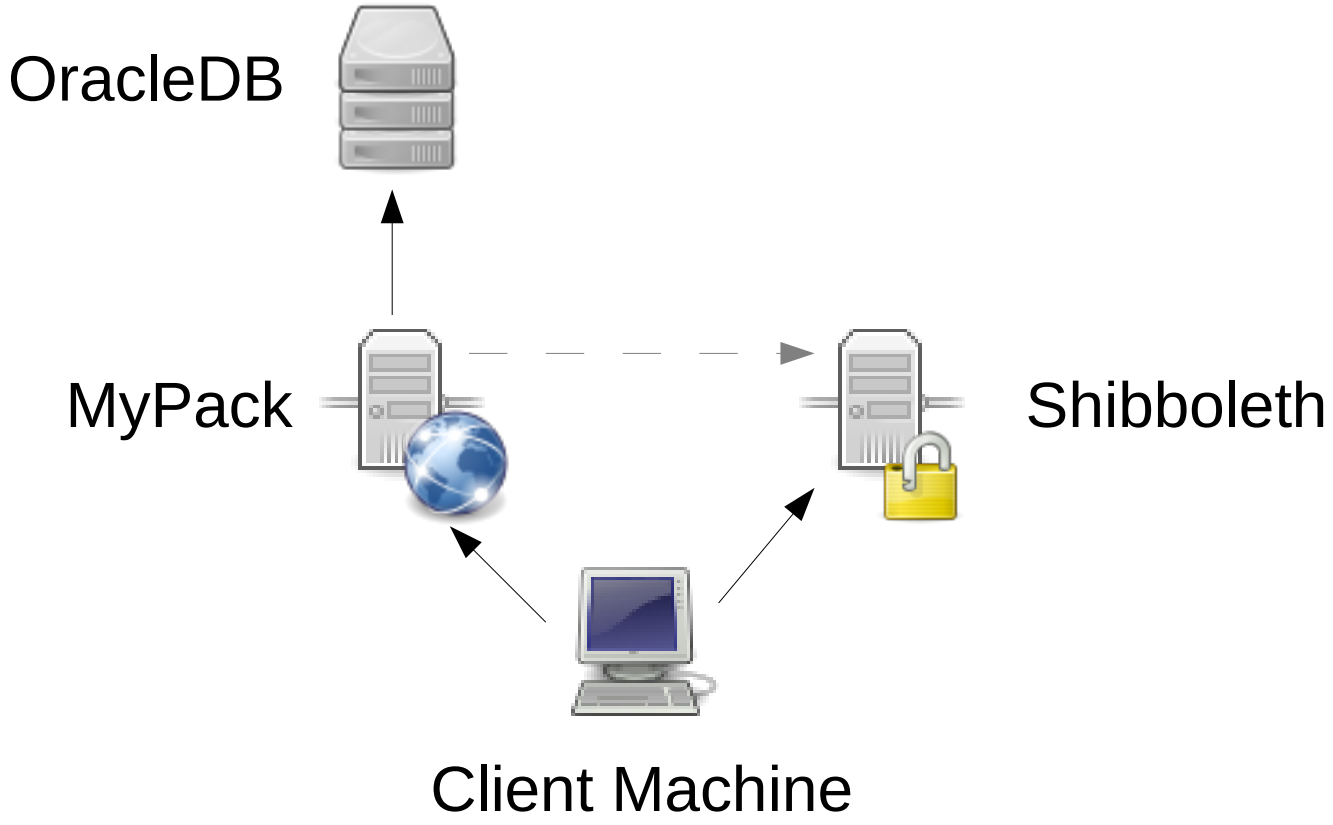
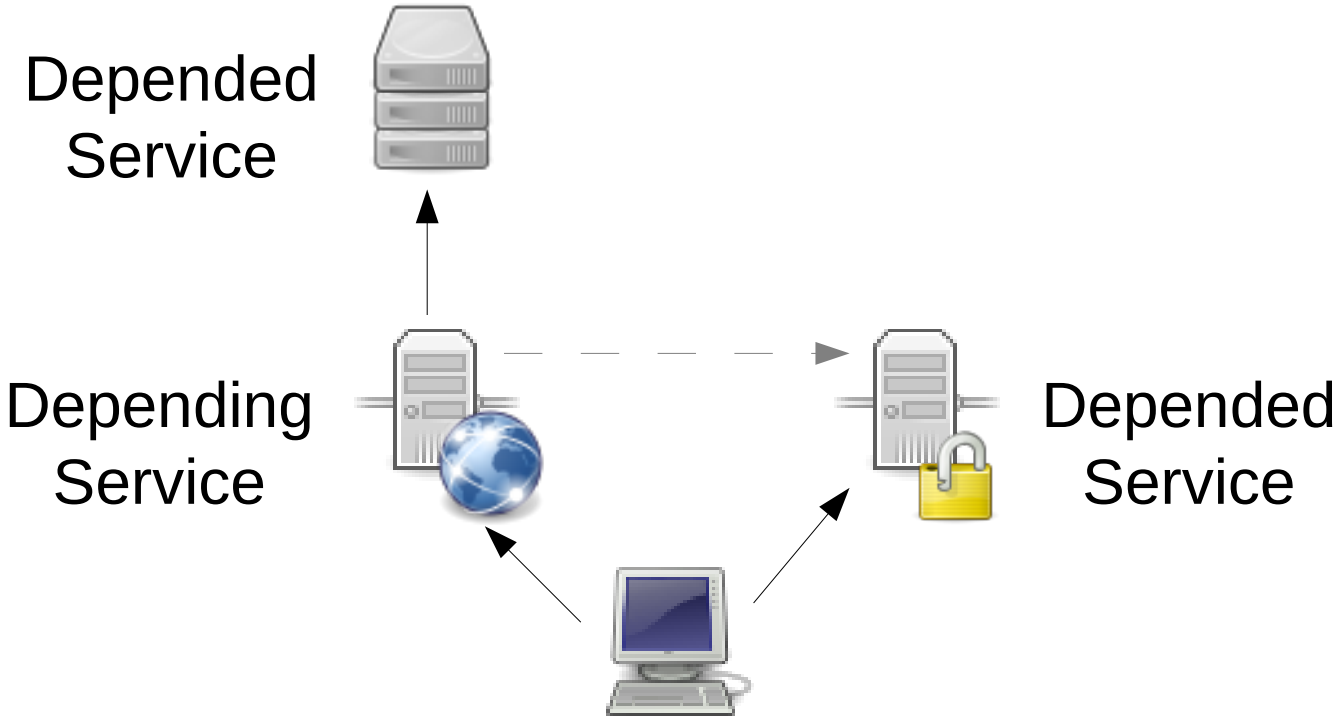
- Enterprise networks are comprised of many network services
- These network services depend on other network services for functionality and information
- This can create a complex web of interdependencies

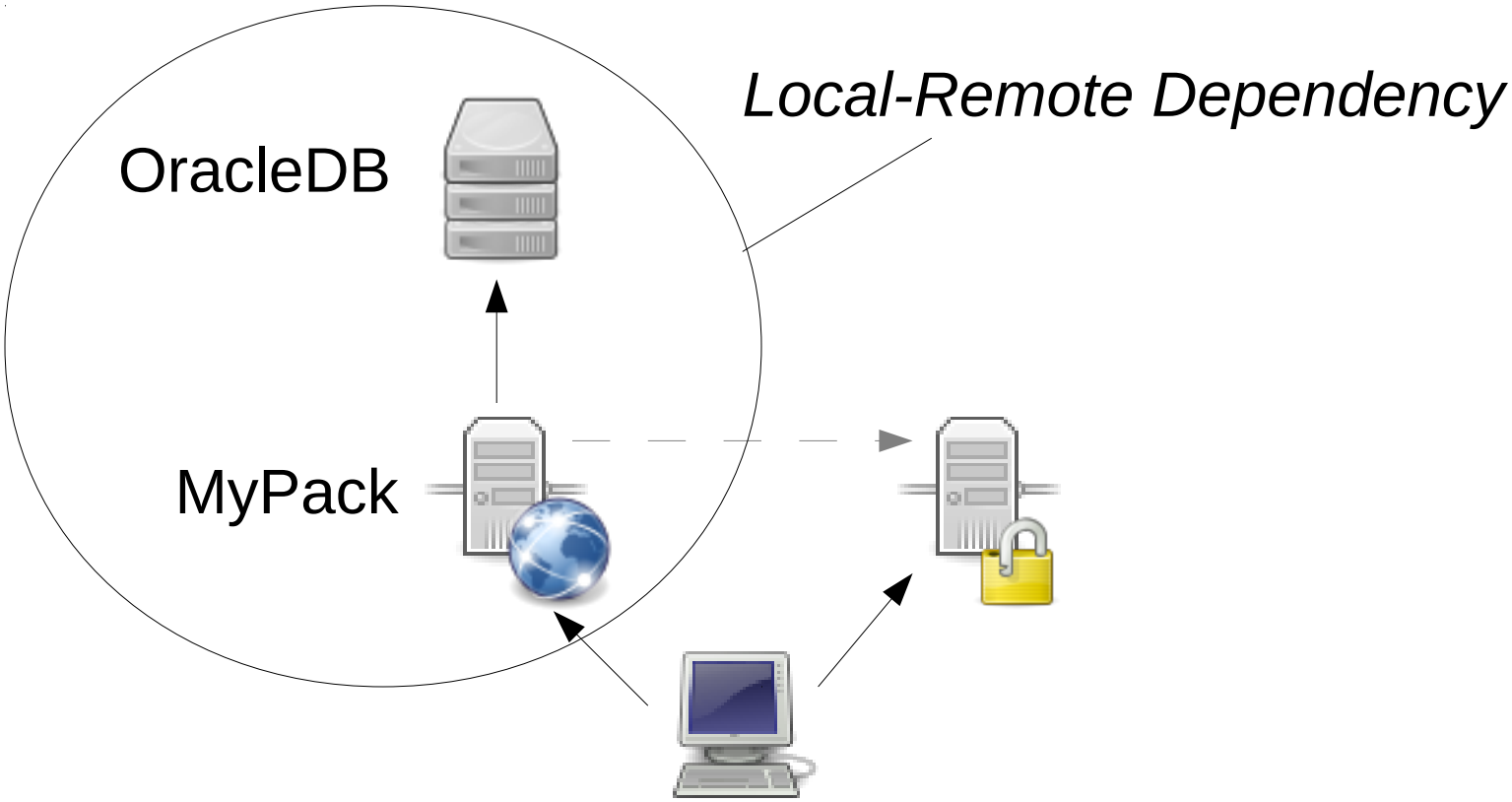
Network Service Dependencies



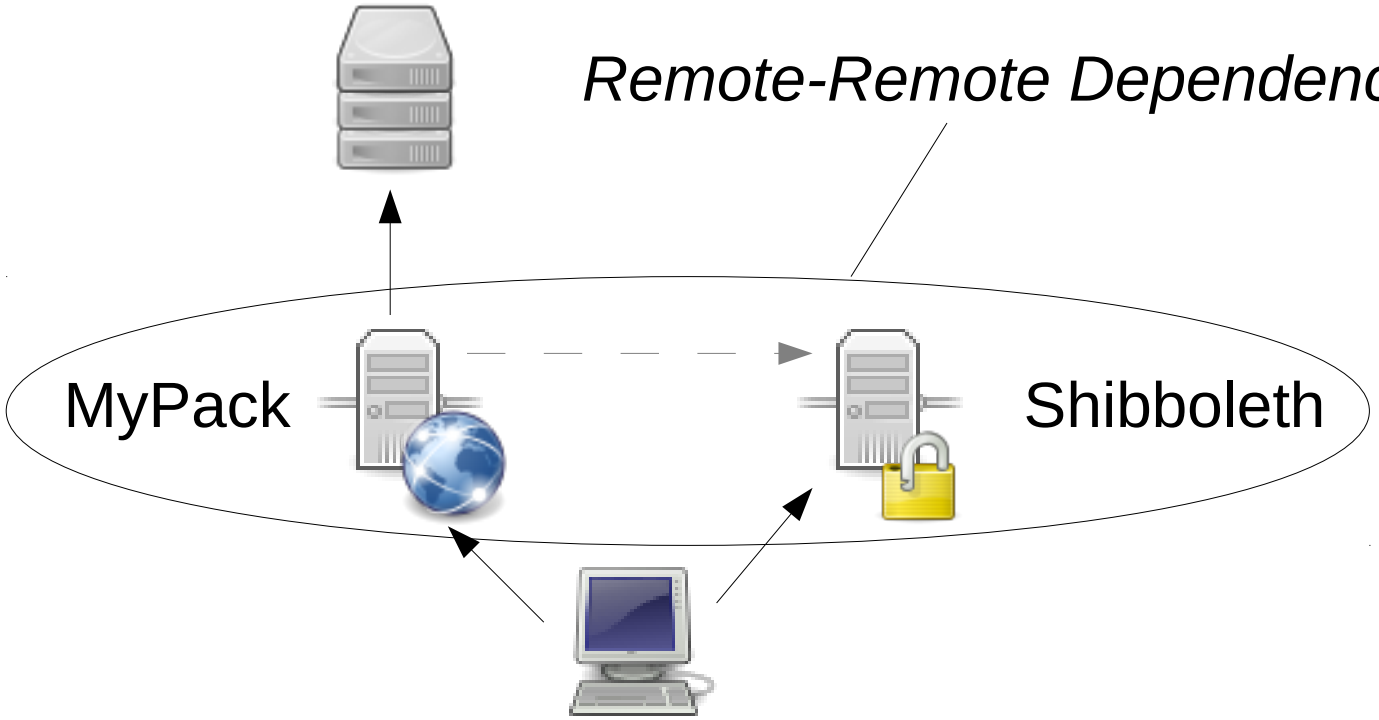
Network Service Dependencies



Network Service Dependencies



Network Service Dependencies



Motivation

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- If a server goes down, it can potentially take down any of its depending services
- Knowing dependencies...
  - makes it easier to react to reports of system failures
  - makes it easier to identify critical components in order to harden them (through redundancy, etc)
- Automatic approaches can cope with changing configurations better than manual analysis

Intuition

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- Most dependencies are explicitly defined in network service configuration files
- Automated approaches look for traffic patterns that suggest dependency relationships
- If there is a dependency between services in a network, patterns will be apparent between them

Previous Works

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- Host-Based
  - Magpie [OSDI 2004]
  - Pinpoint [NSDI 2004]
  - Macroscope [CoNEXT 2009]
- Network Based
  - Sherlock [SIGCOMM 2007]
  - eXpose [SIGCOMM 2008]
  - Orion [OSDI 2008]
  - NSDMiner [INFOCOM 2011]

NSDMiner

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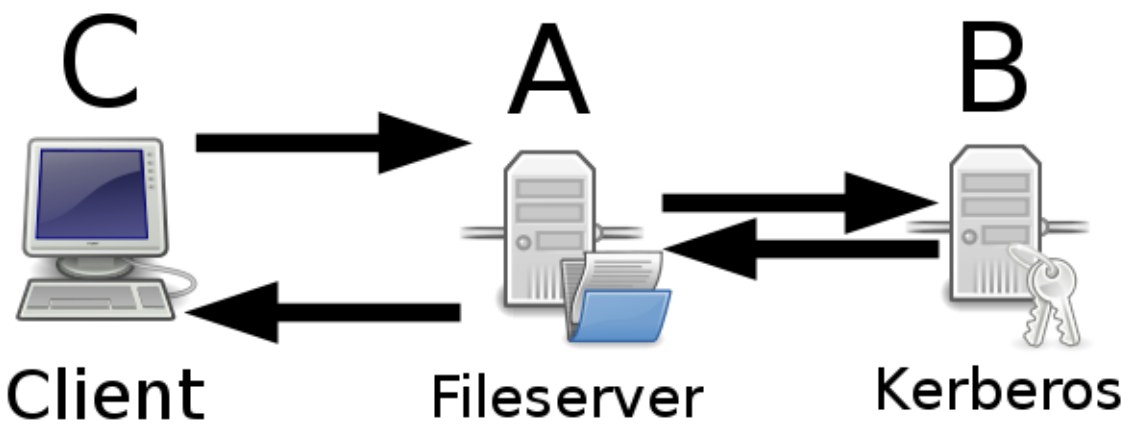
- NSDMiner [INFOCOM 2011] is an effective network-based approach for finding dependencies
- Looks for nested network flows
- Unobtrusive and more accurate than prior work



Limitations of Prior Work

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- Ranking of dependency candidates is unintuitive
  - Should true positives have less than 30% confidence?
  - Causes high false positives
- Hard to identify dependencies of infrequently used services
- Can't automatically take advantage of overall server configurations
  - Similar services
  - Redundant service clusters

Our Contributions

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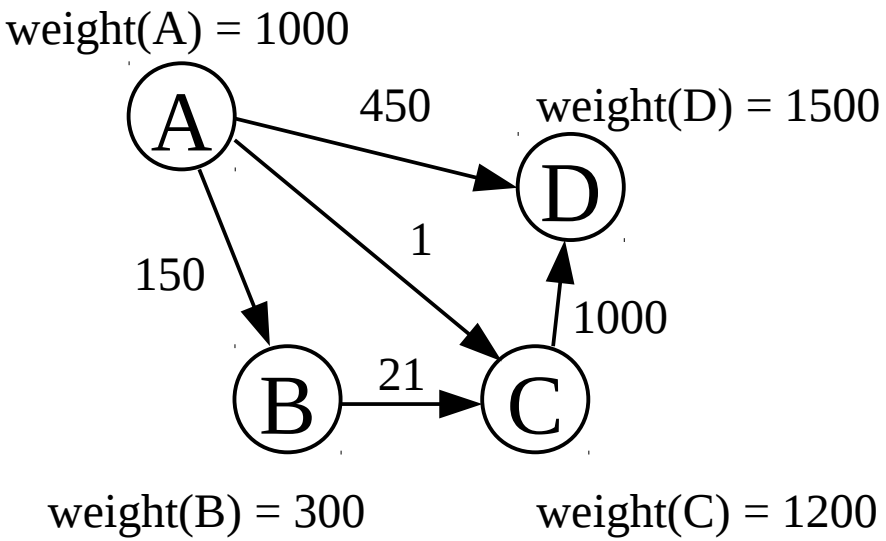
- We develop three novel approaches to improving the detection of network service dependencies
  - A logarithmic based ranking scheme that reduces false positives
  - An inference technique that discovers dependencies of infrequently used services
  - An approach to identify redundant clusters of services in a network
- We implement these as extensions to NSDMiner and evaluate them on production network traffic

Ratio Ranking

- NSDMiner originally uses a *ratio-based ranking*
- *Confidence* is *weight(edge)/weight(node)*
  - weight(A) = number of times A is accessed
  - weight(A → B) = number of nested flows from A to B



Ratio Ranking (cont)

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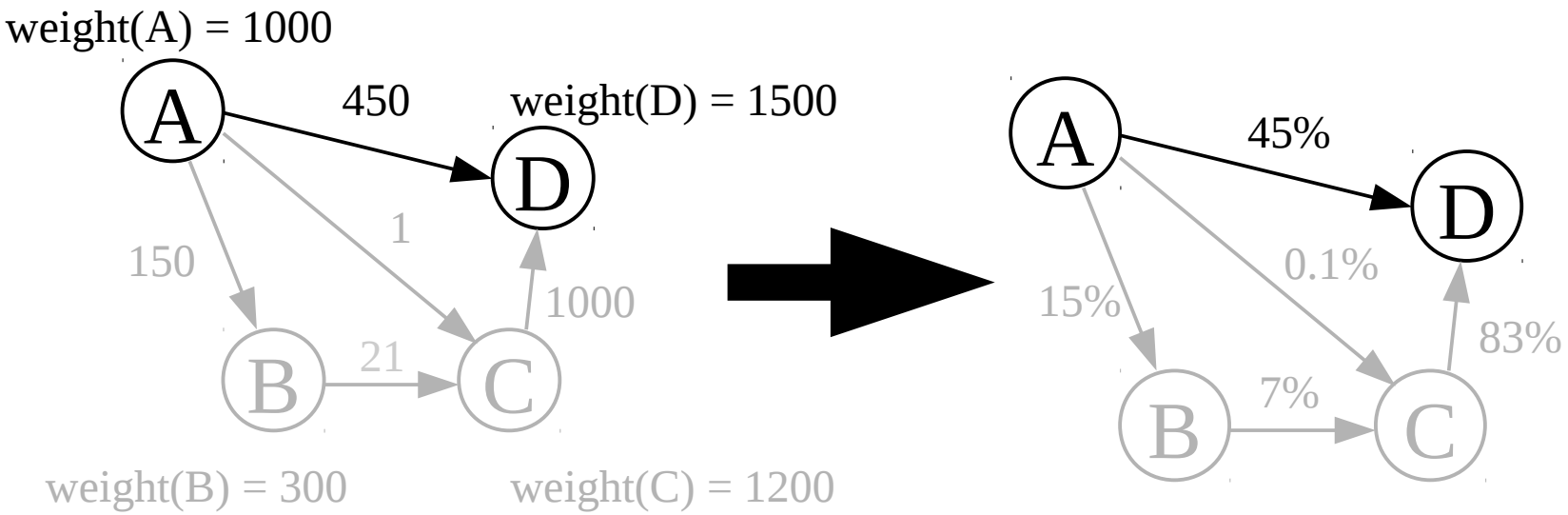
Consider A → D: even though a nested flow to D occurs *every other time* A is accessed, it is only given a confidence of less than 45%.



Ratio Ranking (cont)

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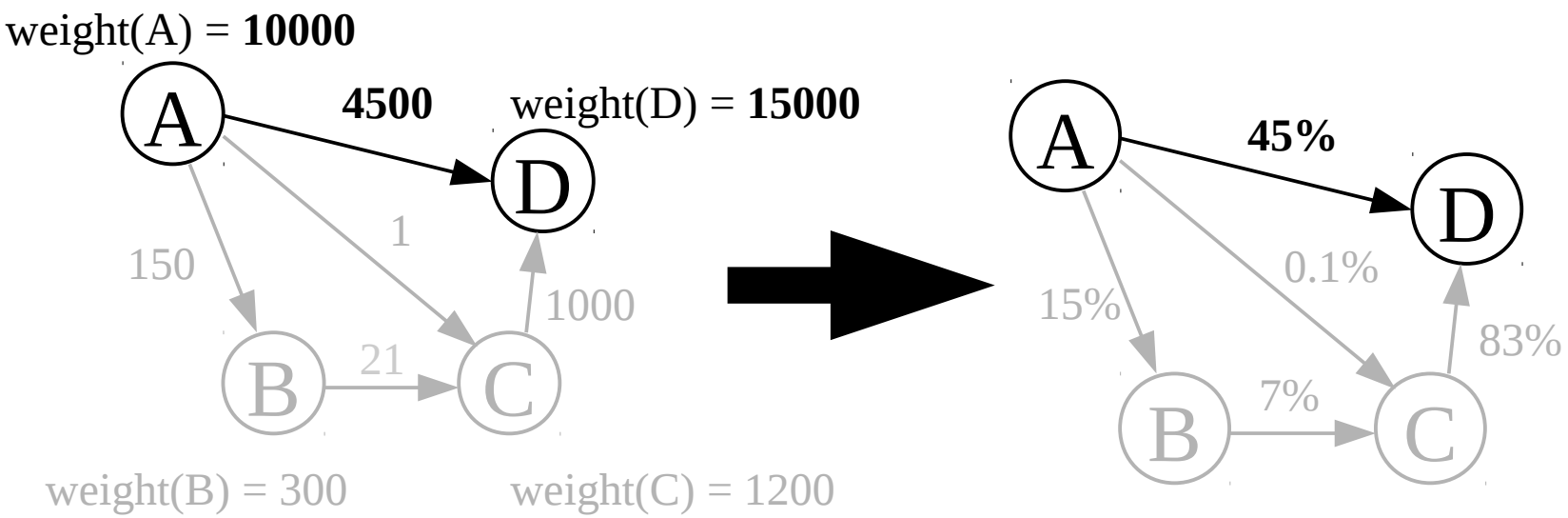
Even if the weights are increased by 10x, the confidence remains the same.



Ratio Ranking (cont)

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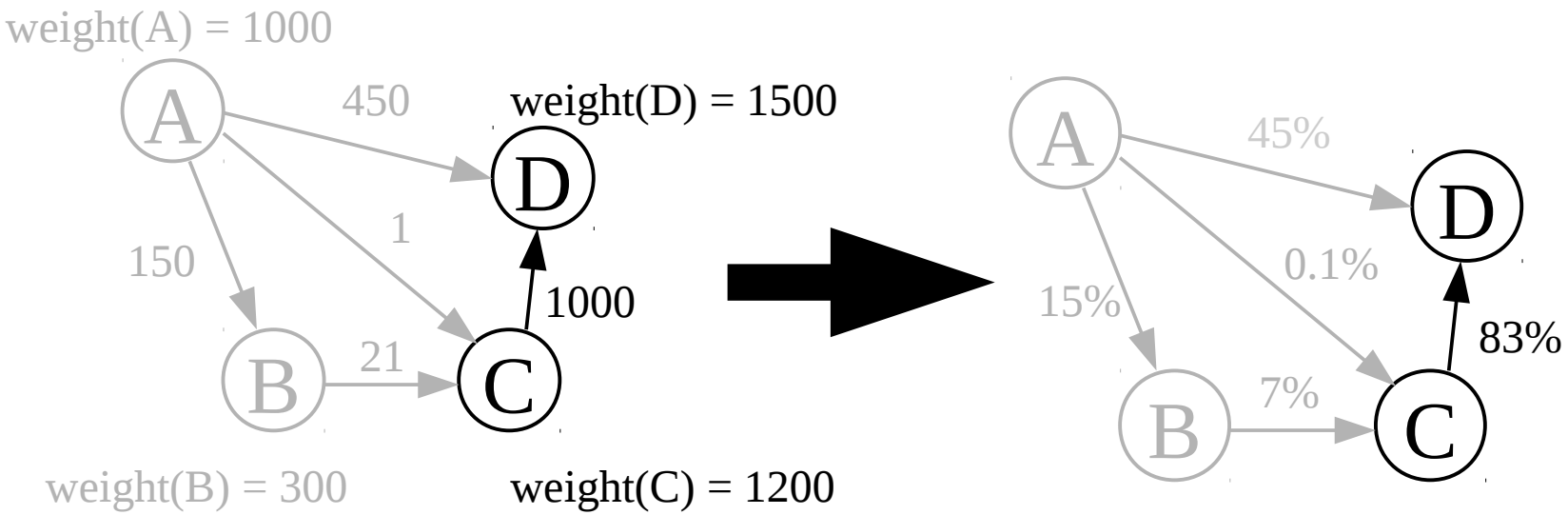
Furthermore, consider C → D: The confidence is very high. Would an additional 100 nested flows result in any more confidence?



Ratio Ranking (cont)

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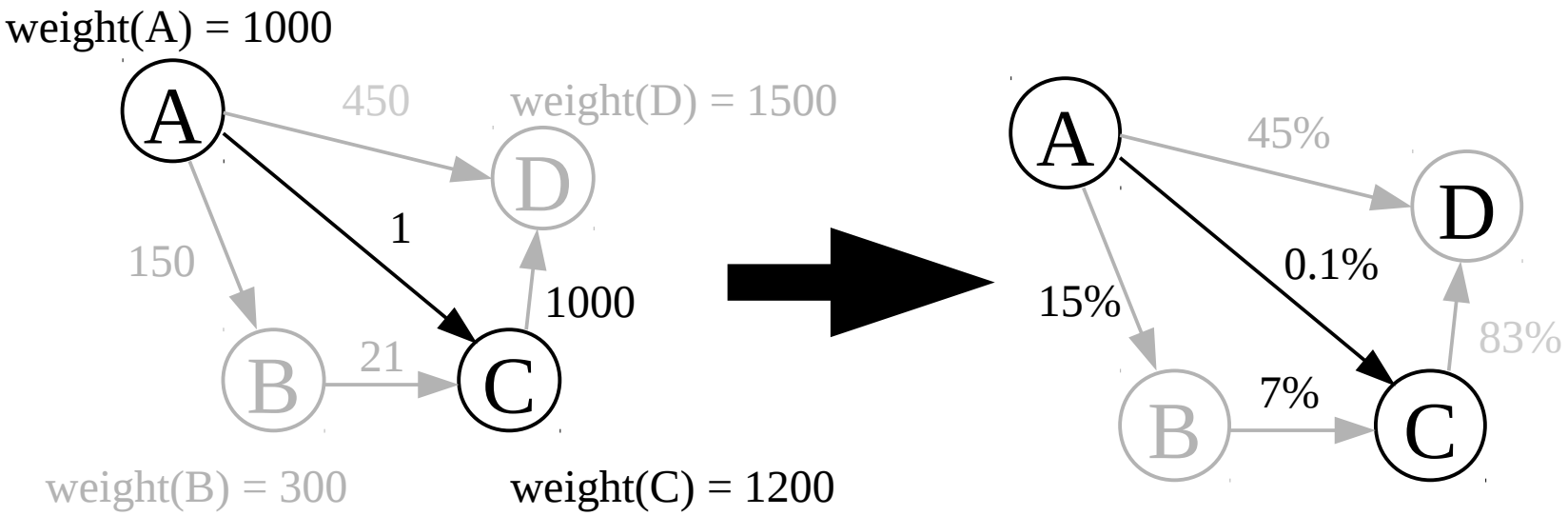
On the other hand, seeing 100 nested flows from A to C would be be substantially more convincing, yet the confidence would grow at roughly the same rate



Logarithmic Ranking

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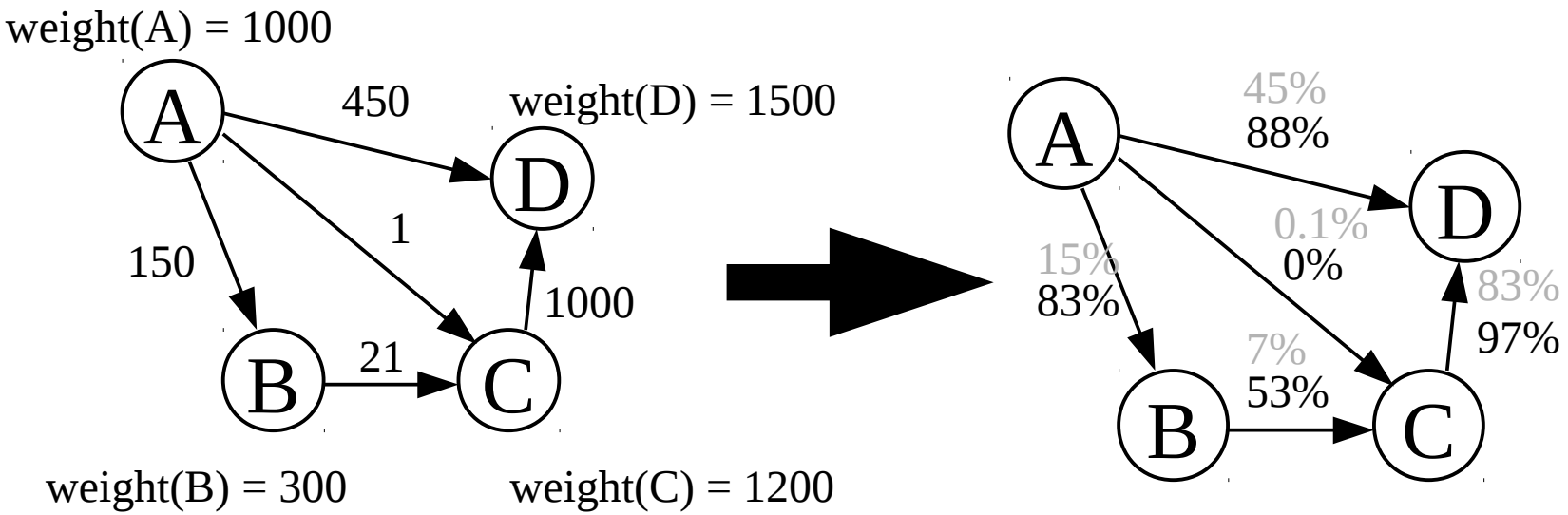
- Three issues with Ratio Ranking
  - Results in low, unintuitive confidence values
  - Having more traffic that exhibits the same behavior should give us more confidence
  - As more nested flows are observed, the rate of confidence growth should decrease
- Instead, set confidence = $log_{weight(node)} weight(edge)$
  - Equivalent to *log(weight(node))/log(weight(edge))*
- Puts more disparity between true/false positives

Logarithmic Ranking (cont.)

- Logarithm implicitly gives higher values to the same ratio with greater magnitude
- Logarithm also grows quickly before leveling off



Service Inference

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- In many networks, there are several hosts offering different instances of the same service
- Some of these services may be accessed more frequently than others
- If we can identify that two instances of services are the same type, we can infer the dependencies of a rarely used service from one that's used often
- We determine similarity using the overlap in their depended services

Service Inference (example)

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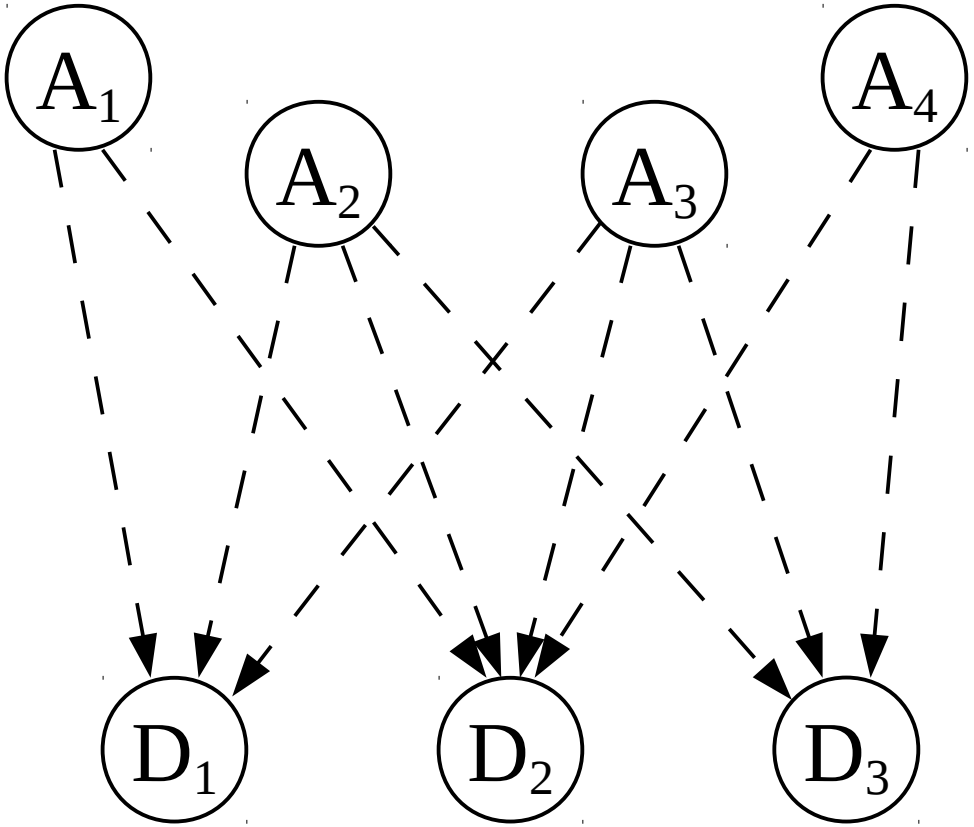
We begin with a communication graph. In this case, weights are not relevant.



Service Inference (example)

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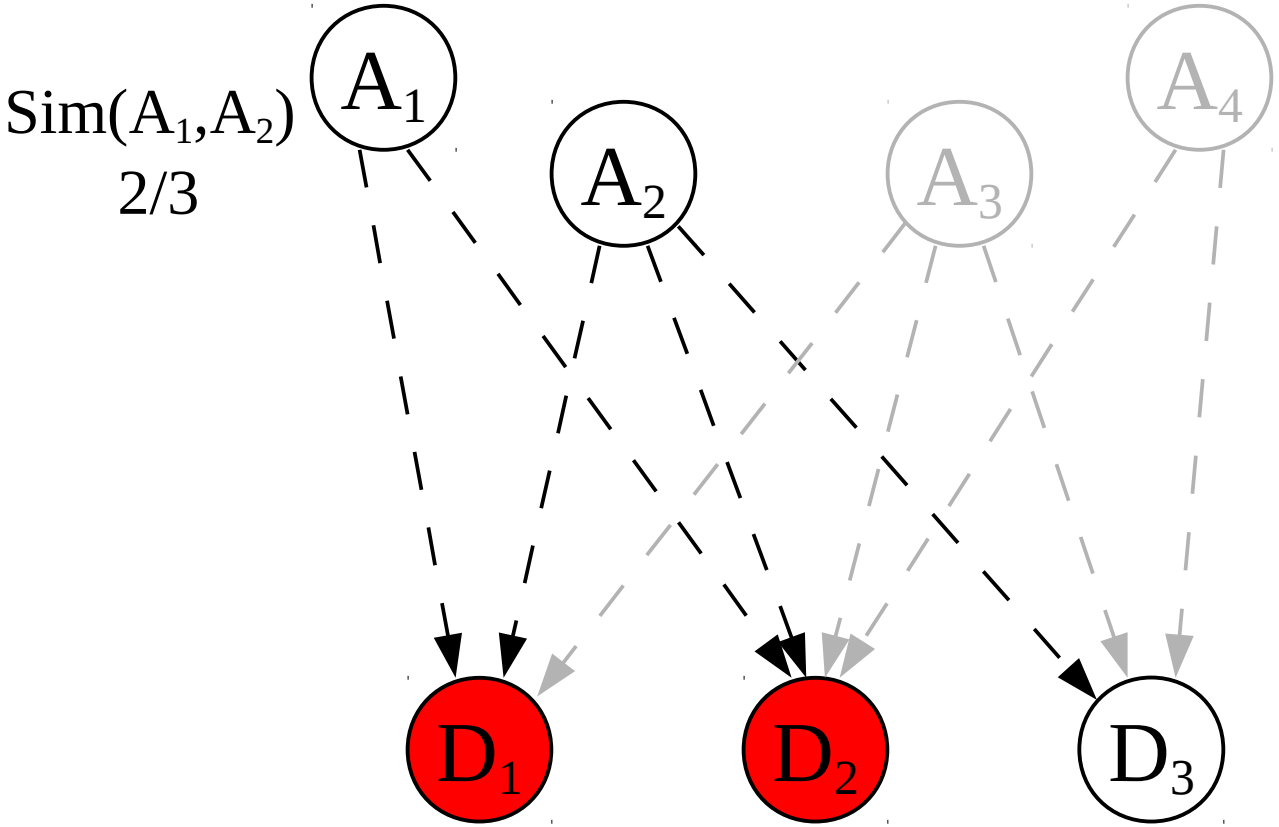
The similarity of two services is defined as the number of common depended services over number of dependencies of the service with the greater number of dependencies.



Service Inference (example)

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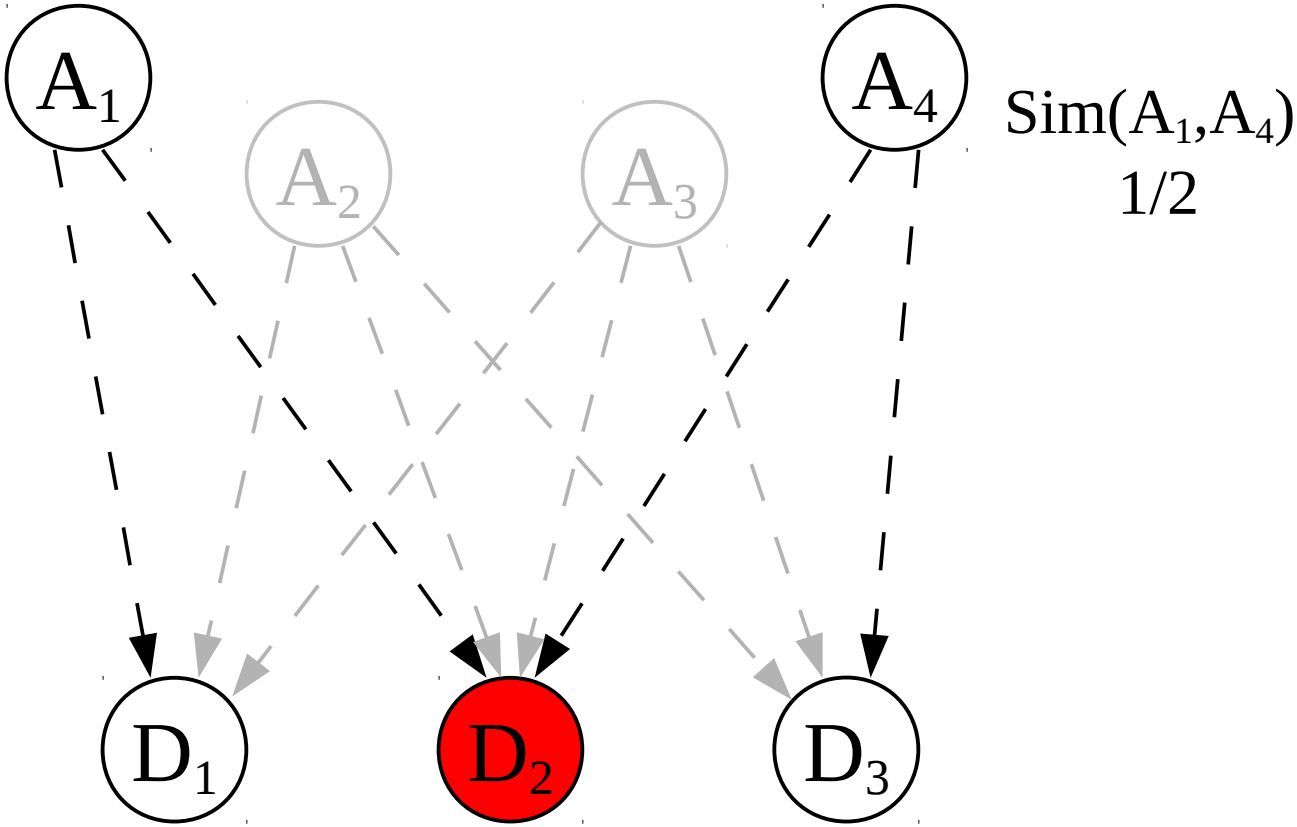
The similarity of two services is defined as the number of common depended services over number of dependencies of the service with the greater number of dependencies.



Service Inference (example)

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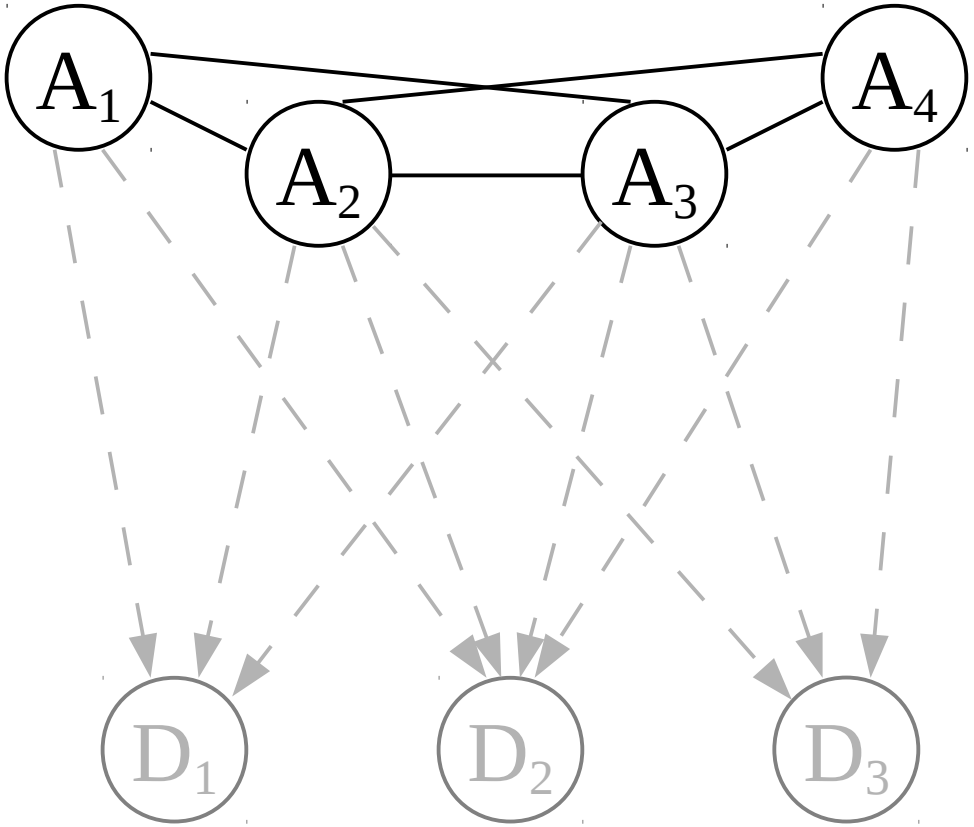
We draw edges between all similar services. Each connected subgraph is considered a similar “group”.



Service Inference (example)

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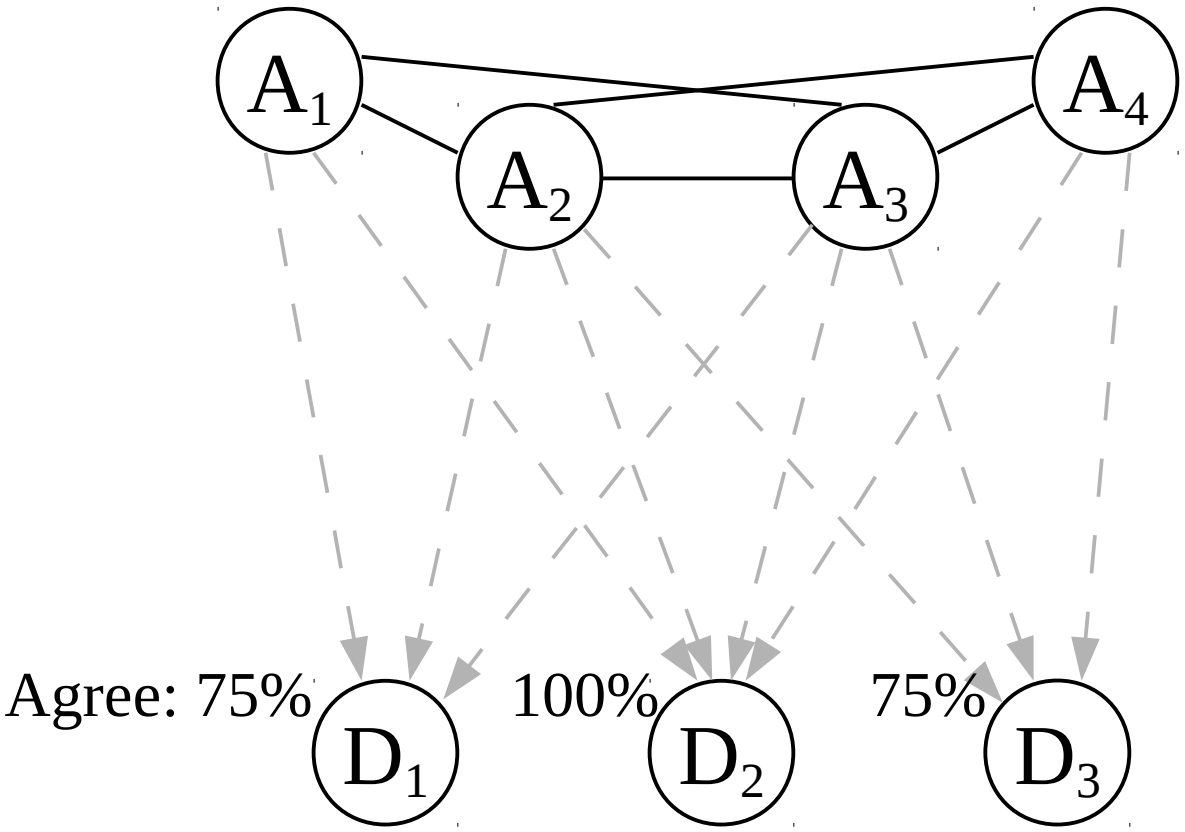
The agreement of a service is equal to the fraction of members of the group that depend on it.



Service Inference (example)

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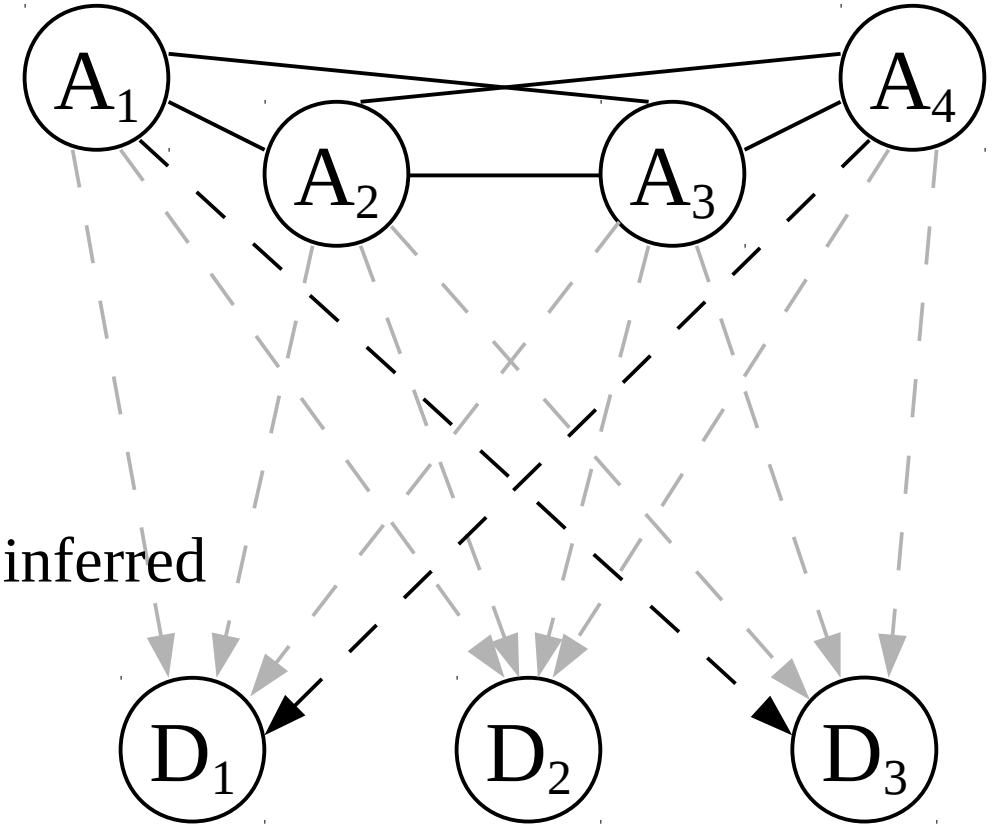
Any service in the group that does not depend on an agreed depended service has that dependency inferred.



$A_4 \rightarrow D_1$ and
$D_1 \rightarrow D_3$ are inferred

Service Inference (cont)

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- This approach is configured with two thresholds:
- The similarity threshold
  - Defines how large groups of similar services become
- The agreement threshold
  - Defines how many dependencies are inferred from these groups
- In networks with lots of redundancy, high thresholds can still yield usable results

Cluster Discovery

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- Network services often rely on redundant service clusters
  - Nodes in load-balancing service cluster can be used interchangeably by depending services
  - Nodes in back-up clusters will replace primary nodes in the event that they fail
- In both cases, the services in a cluster will appear in a list of depended services together
- We use this observation to drive our approach to discovering service clusters

Cluster Discovery (example)

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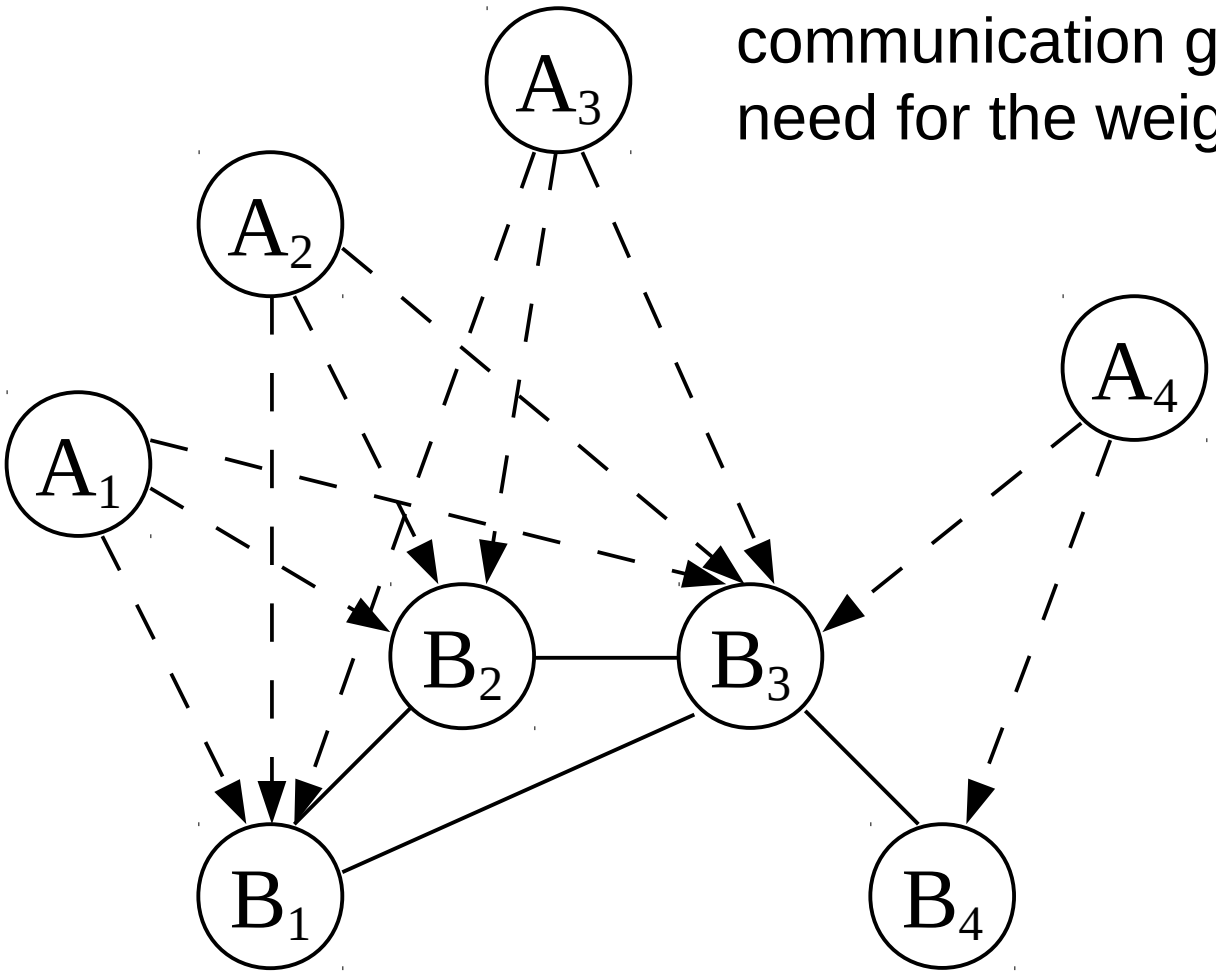
Again, we begin with a communication graph without any need for the weights.



Cluster Discovery (example)

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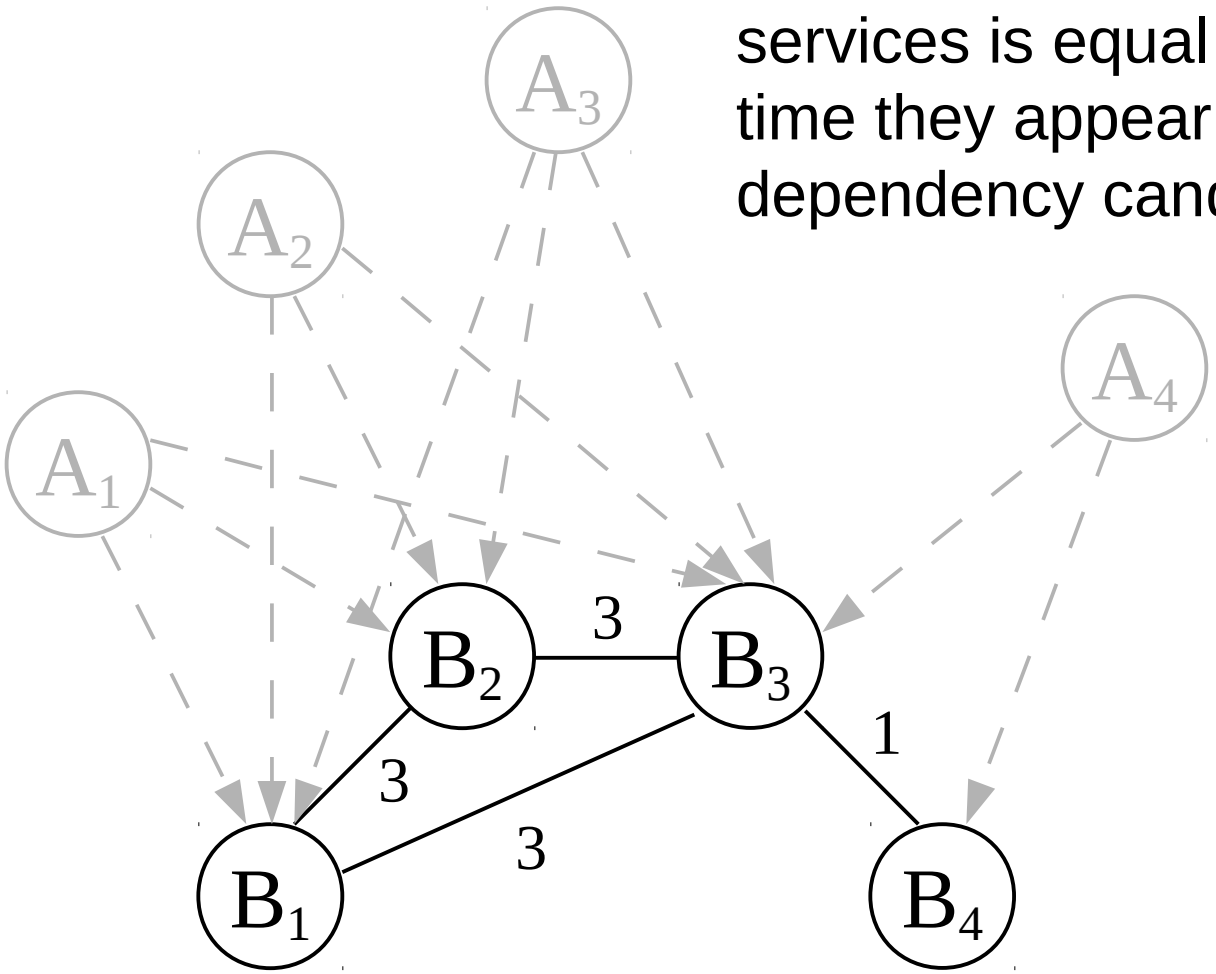
The support of a pair of depended services is equal to the number of time they appear together as dependency candidates.



Cluster Discovery (example)

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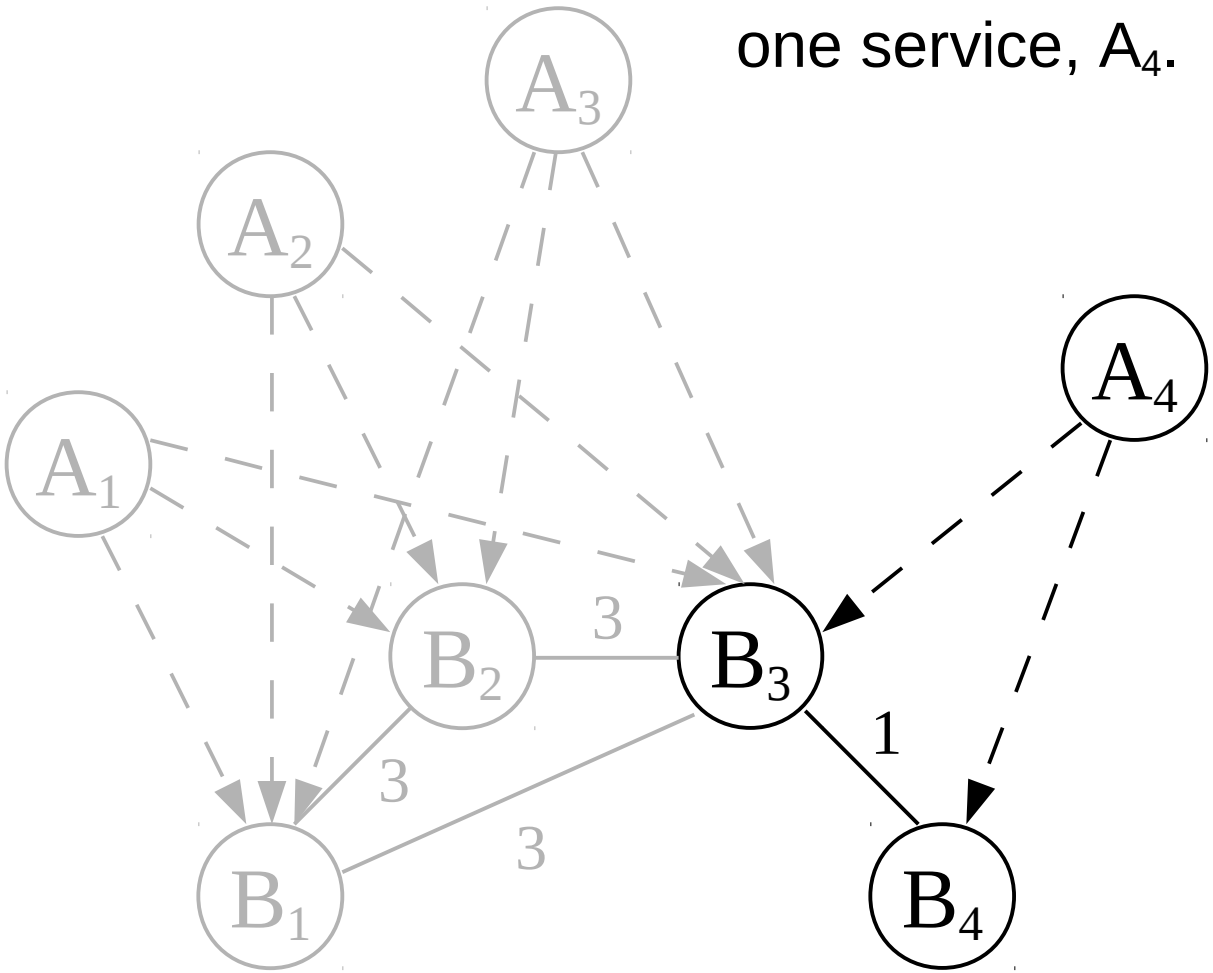
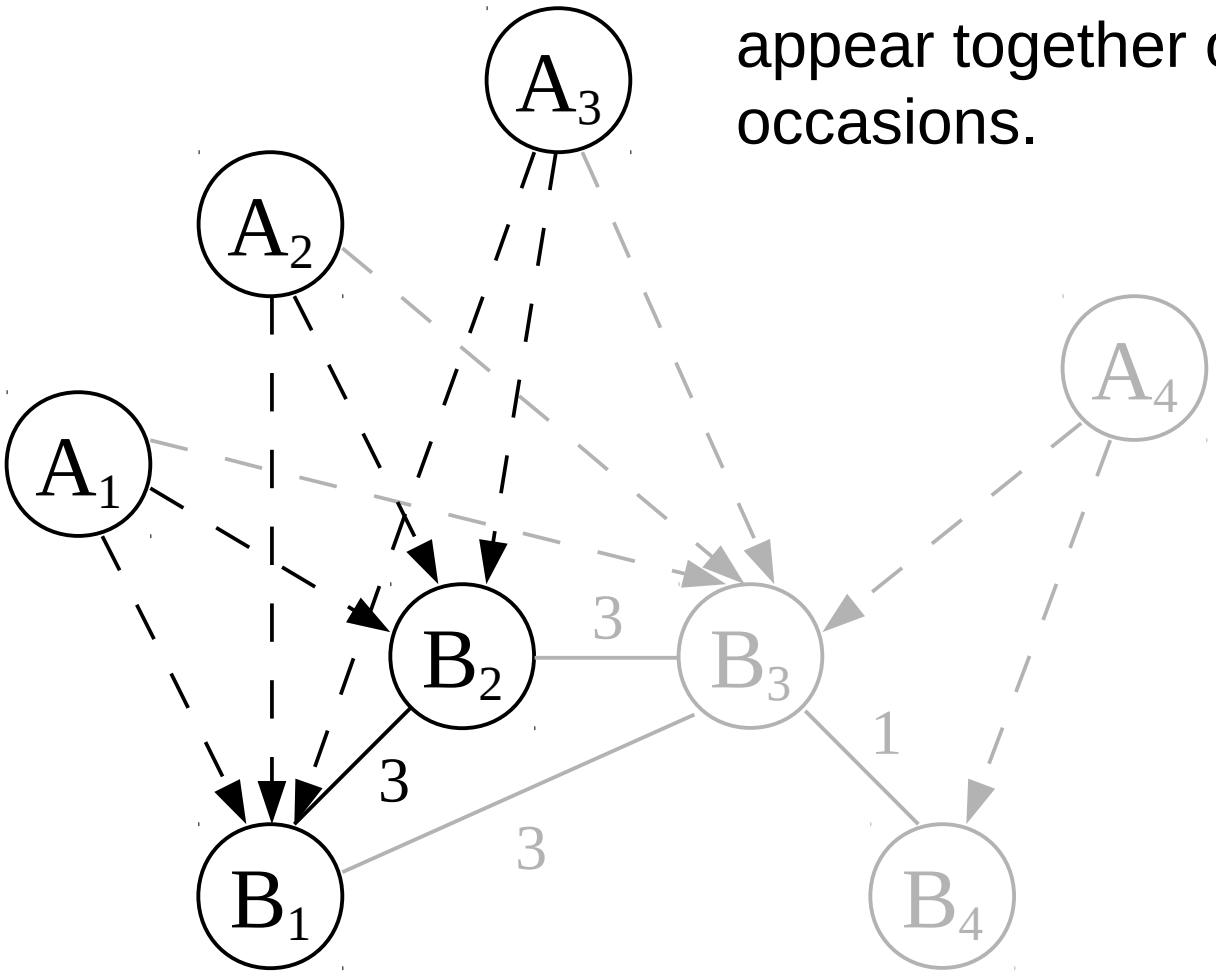
B_3 and B_4 only appear together for one service, A_4.



Cluster Discovery (example)



On the other hand, B_1 and B_2 appear together on three separate occasions.

Cluster Discovery (example)

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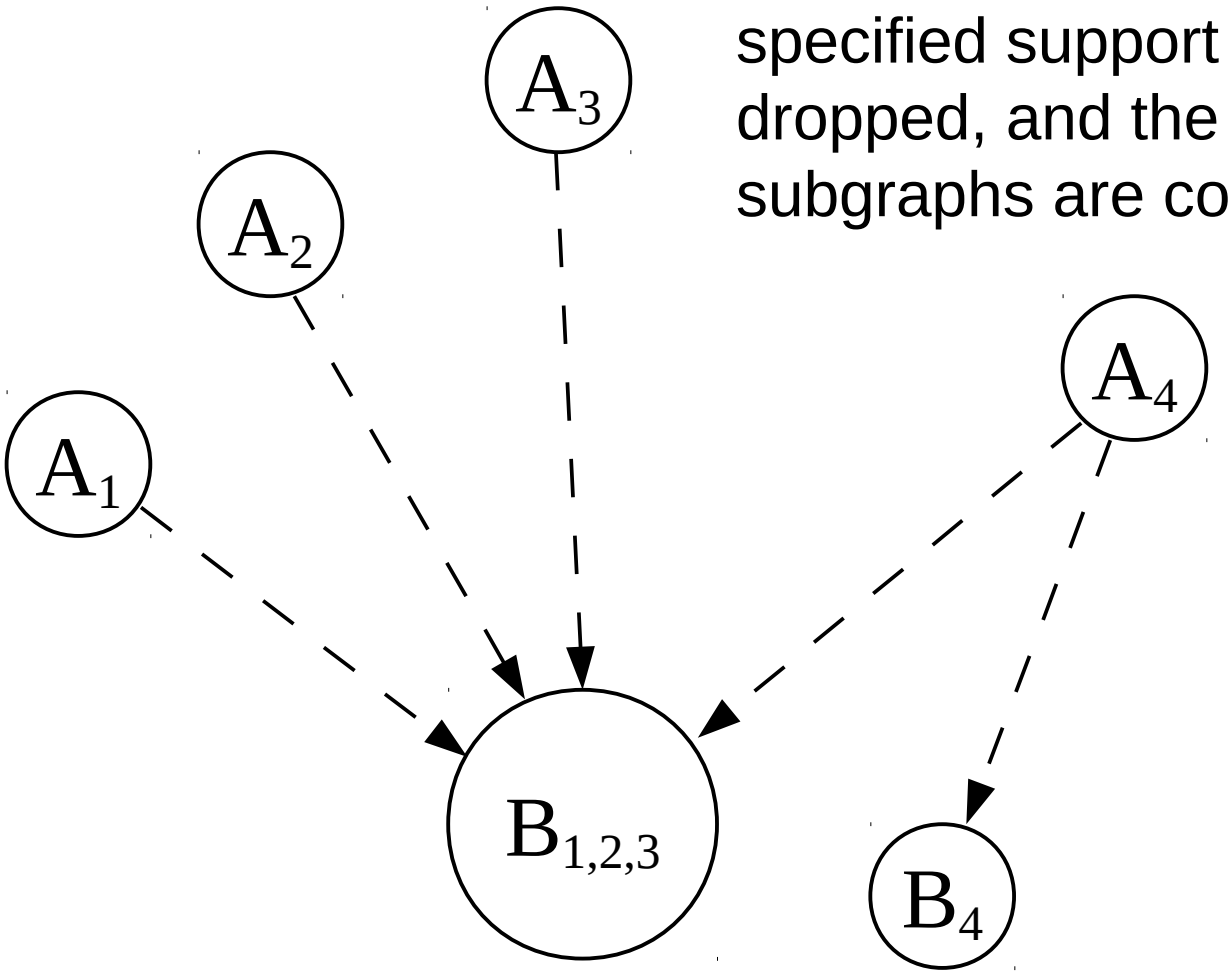
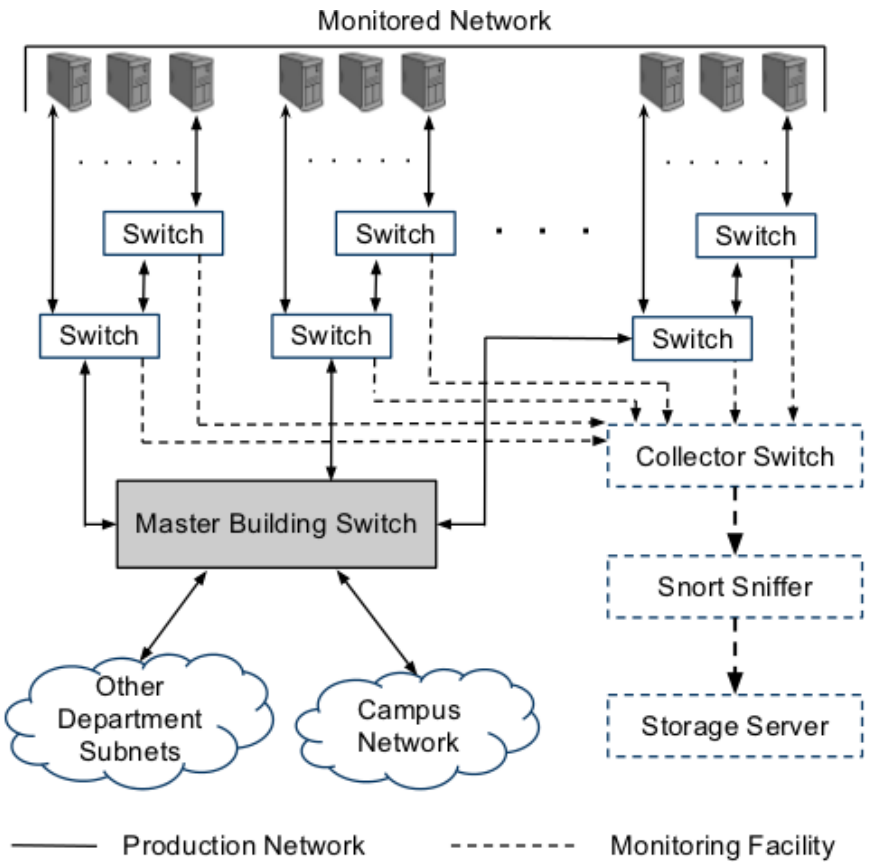
Any edges with less than a user-specified support threshold are dropped, and the connected subgraphs are considered clusters.



Evaluation

- We evaluate on the same dataset as NSDMiner's 2011 iteration
- Collected from the traffic on the second floor of EB2's CSC wing
- Ground truth built with help from CSC IT



Logarithmic Ranking

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- Logarithmic ranking was an improvement, especially for infrequently used services

	Shared Mode						Exclusive Mode					
	Ratio (0.5%)			Log (45%)			Ratio (0.5%)			Log (44%)		
Service	TP	FP	FN	TP	FP	FN	TP	FP	FN	TP	FP	FN
webservice	8	9	1	9	12	0	8	4	1	8	7	0
email	3	1	0	3	3	0	3	0	0	3	2	0
ssh(realm-4)	10	1	0	10	1	0	10	1	0	10	1	0
ssh(realm-5)	41	14	10	43	12	8	40	10	11	43	9	8
svn	4	1	0	4	0	0	4	1	0	4	0	0
proxy DHCP	2	1	0	2	0	0	2	1	0	2	0	0
DHCP	1	6	0	1	1	0	1	6	0	1	1	0
endpoint mapper	6	43	0	6	4	0	3	6	3	3	1	3
WDS (RPC)	4	10	0	3	1	1	4	1	0	2	0	2
DFS replication (RPC)	8	4	0	6	3	2	7	0	1	5	1	3
SMB	9	7	1	9	9	1	9	3	1	9	5	1
TFTP	-	1	-	-	1	-	-	0	-	-	0	-
database	-	1	-	-	2	-	-	1	-	-	2	-
Invalid Services	-	34	-	-	29	-	-	30	-	-	17	-
Total	96	133	12	96	78	12	91	64	17	90	46	18

Logarithmic Ranking

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- The greatest improvements in False Positives came from services that were infrequently used.

	Shared Mode						Exclusive Mode					
	Ratio (0.5%)			Log (45%)			Ratio (0.5%)			Log (44%)		
Service	TP	FP	FN	TP	FP	FN	TP	FP	FN	TP	FP	FN
webservice	8	9	1	9	12	0	8	4	1	8	7	0
email	3	1	0	3	3	0	3	0	0	3	2	0
ssh(realm-4)	10	1	0	10	1	0	10	1	0	10	1	0
ssh(realm-5)	41	14	10	43	12	8	40	10	11	43	9	8
svn	4	1	0	4	0	0	4	1	0	4	0	0
proxy DHCP	2	1	0	2	0	0	2	1	0	2	0	0
DHCP	1	6	0	1	1	0	1	6	0	1	1	0
endpoint mapper	6	43	0	6	4	0	3	6	3	3	1	3
WDS (RPC)	4	10	0	3	1	1	4	1	0	2	0	2
DFS replication (RPC)	8	4	0	6	3	2	7	0	1	5	1	3
SMB	9	7	1	9	9	1	9	3	1	9	5	1
TFTP	-	1	-	-	1	-	-	0	-	-	0	-
database	-	1	-	-	2	-	-	1	-	-	2	-
Invalid Services	-	34	-	-	29	-	-	30	-	-	17	-
Total	96	133	12	96	78	12	91	64	17	90	46	18

Logarithmic Ranking (cont)

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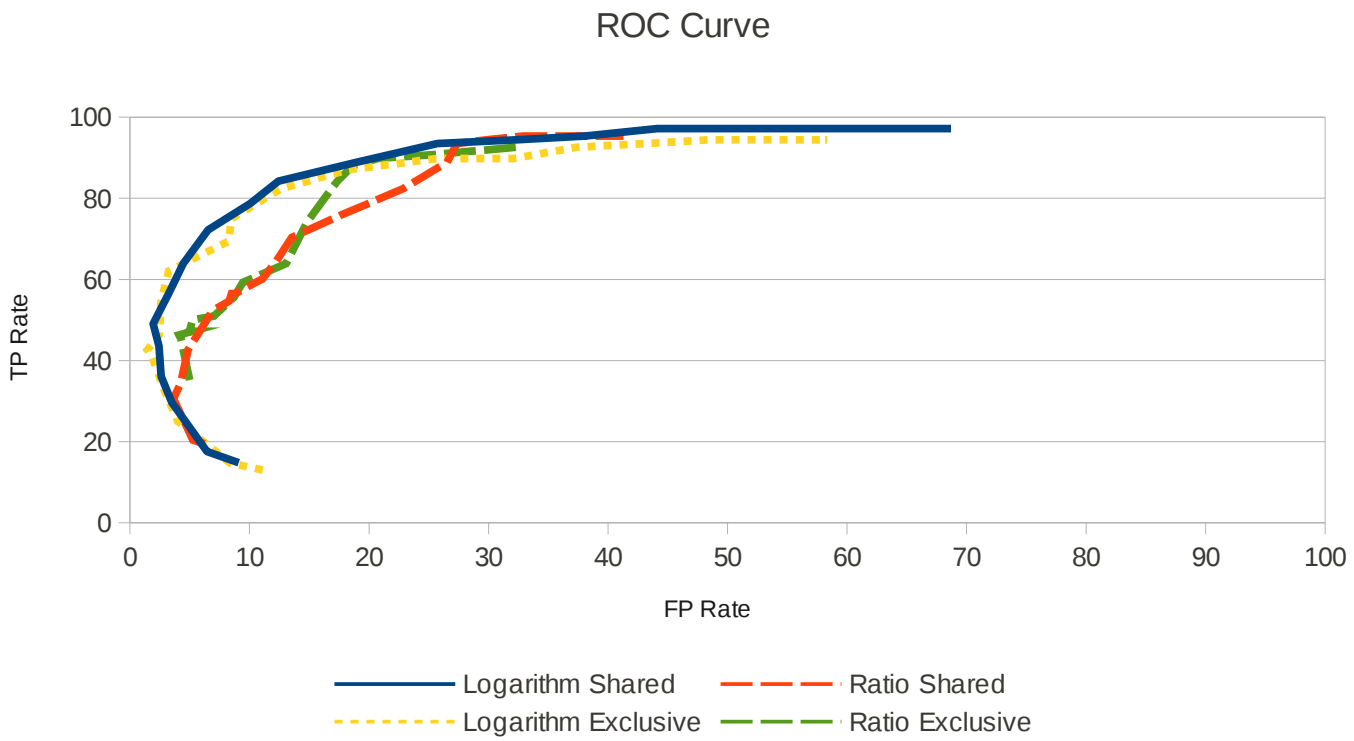
- The Receiver-Operator Characteristic curve shows the overall improvement of log ranking



Logarithmic Ranking (cont)

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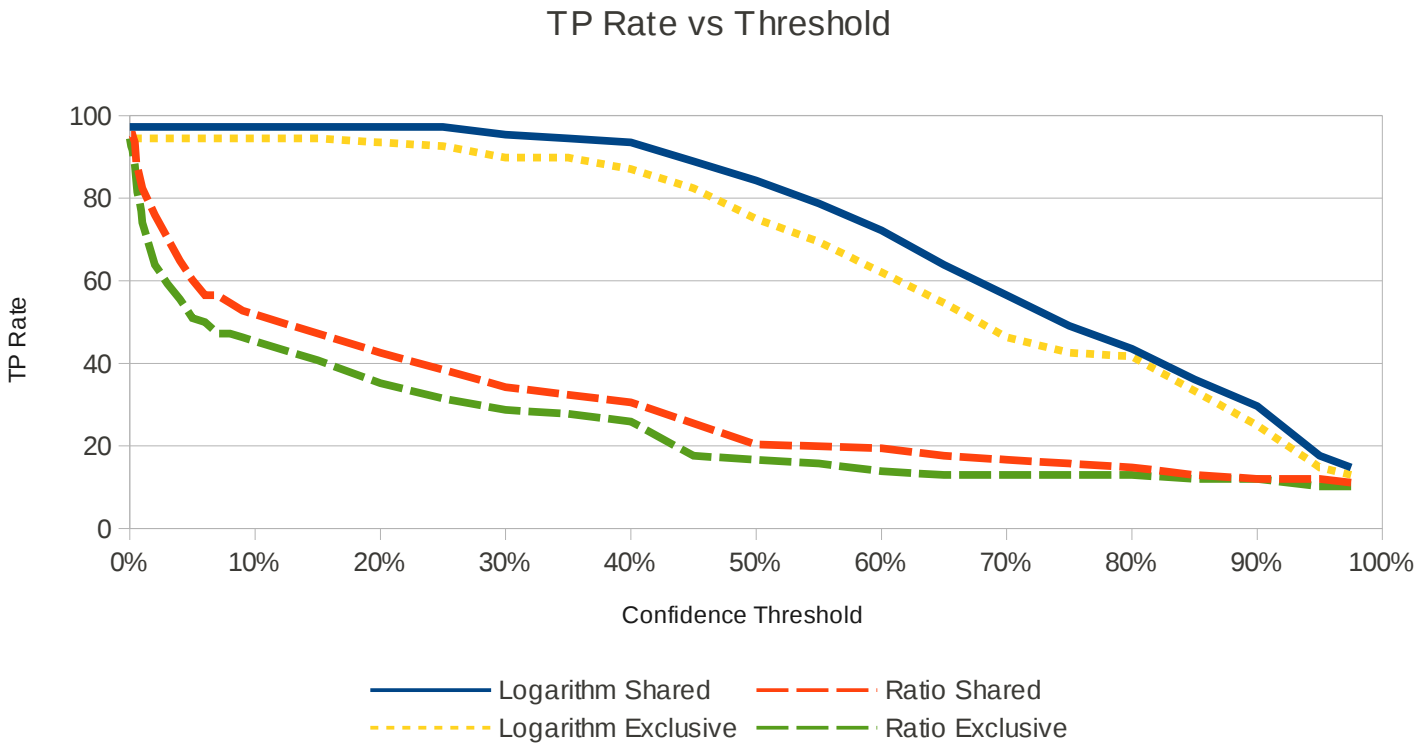
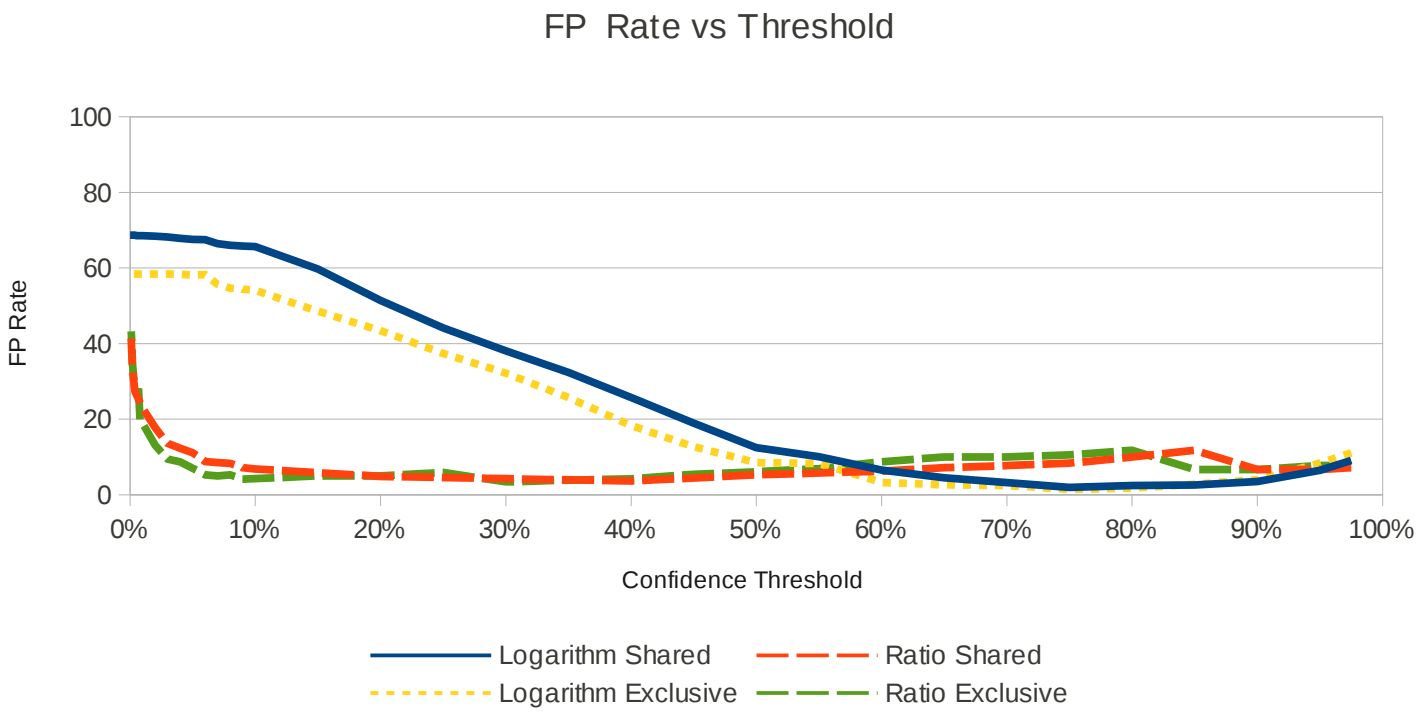
- Note that the number of true positives drops gradually as the confidence threshold increases



Logarithmic Ranking (cont)

- ... as does the False Positive rate



Logarithmic Ranking (cont)

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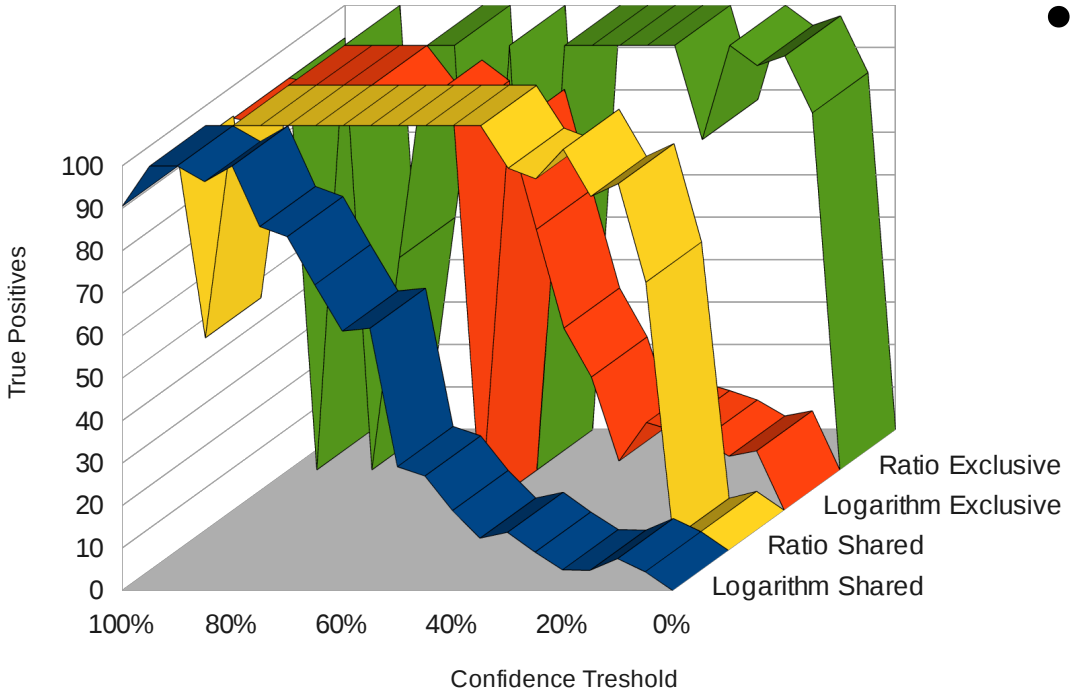
- In logarithmic ranking, the confidence value accurately predicts whether a dependency is true



- This graph shows the candidates divided into bins based on their confidence.

Service Inference

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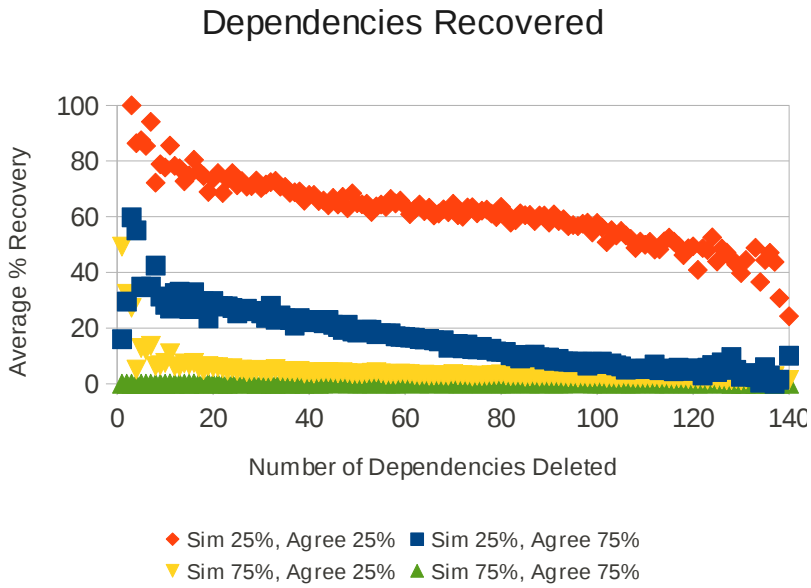
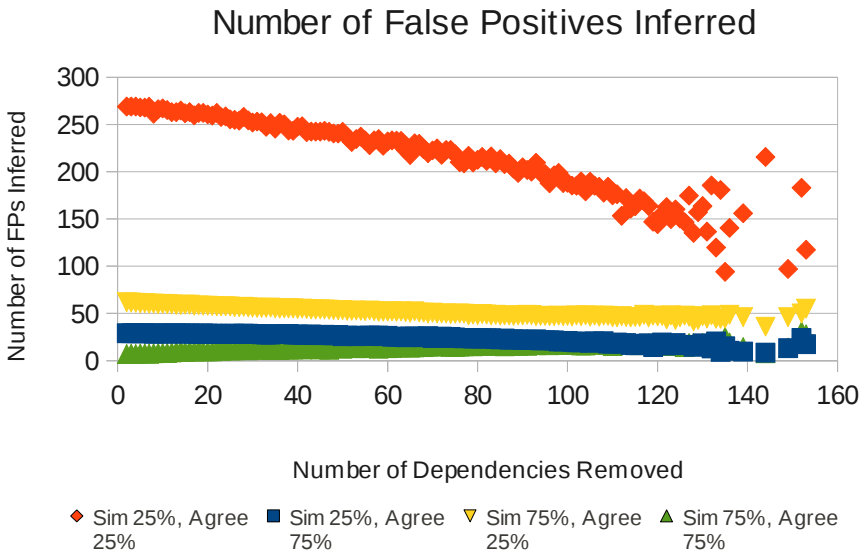
- We removed flows related to some dependencies from the ground truth and tried to re-infer them
- Note that while False positives were inferred, they still had low confidence values (<30%)





Service Inference (cont)

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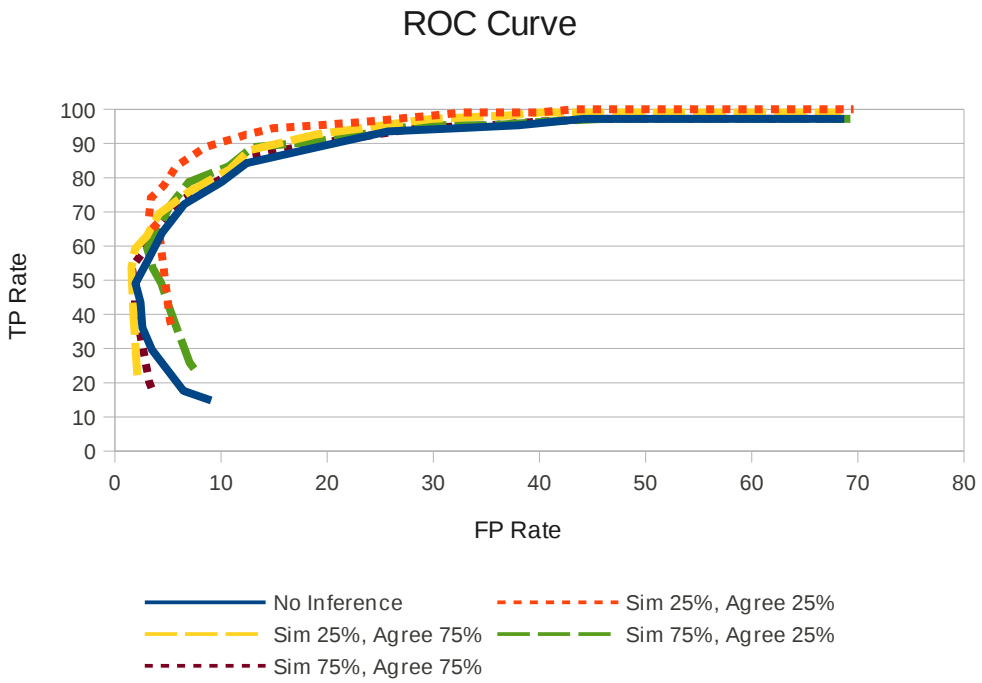
- This shows the ROC curve for various service inference parameters compared to log ranking
- Note that we can achieve 100% coverage!



Cluster Discovery

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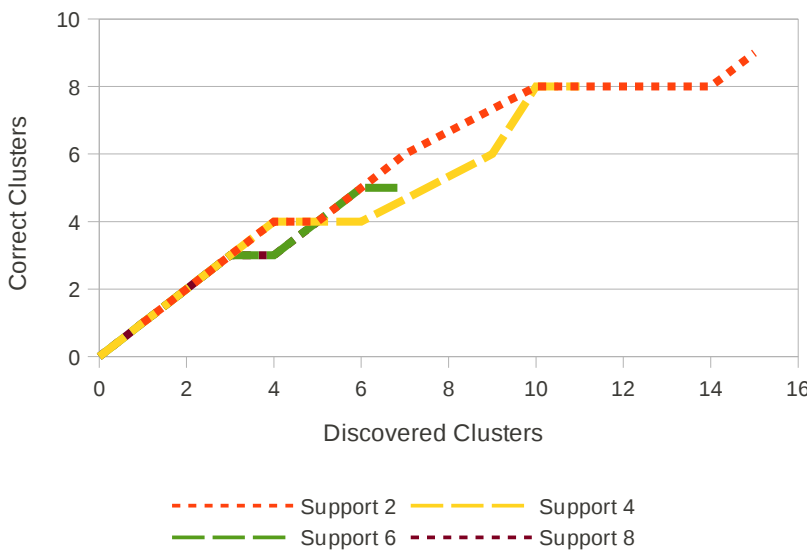
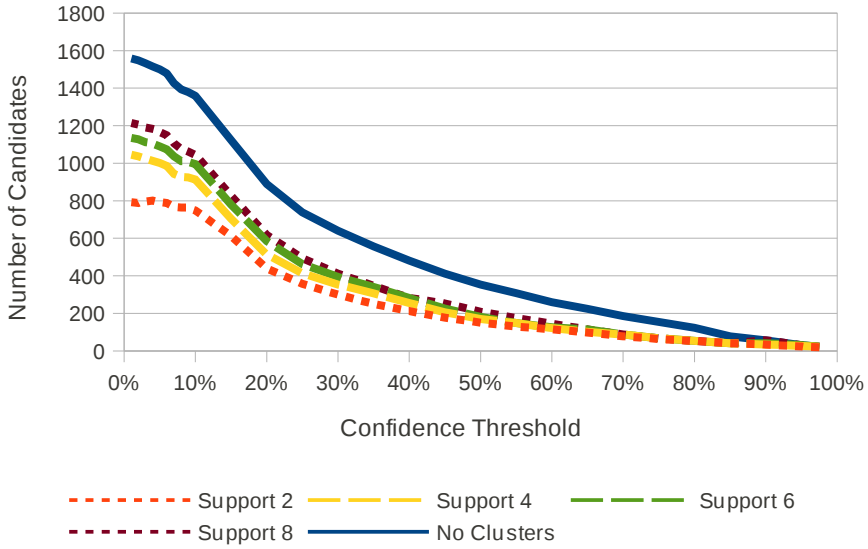
- We accurately detect our network's ten clusters
- By aggregating them, we can reduce the size of the output substantially





In Conclusion...

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- We introduce three novel approaches for the detection of network service dependencies
- We implement and test our approaches on production network traffic
  - Our approach improves false positives and negatives on top of NSDMiner's original improvements

Future Work

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- Identification of remote-remote dependencies
- Ability to monitor dependencies in real time
- Collection of a newer, larger dataset (first and third floor)

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Thank you for your attention!

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