EVA
Evolutionary Vulnerability Analyzer

A Framework for Network Analysis and Risk Assessment

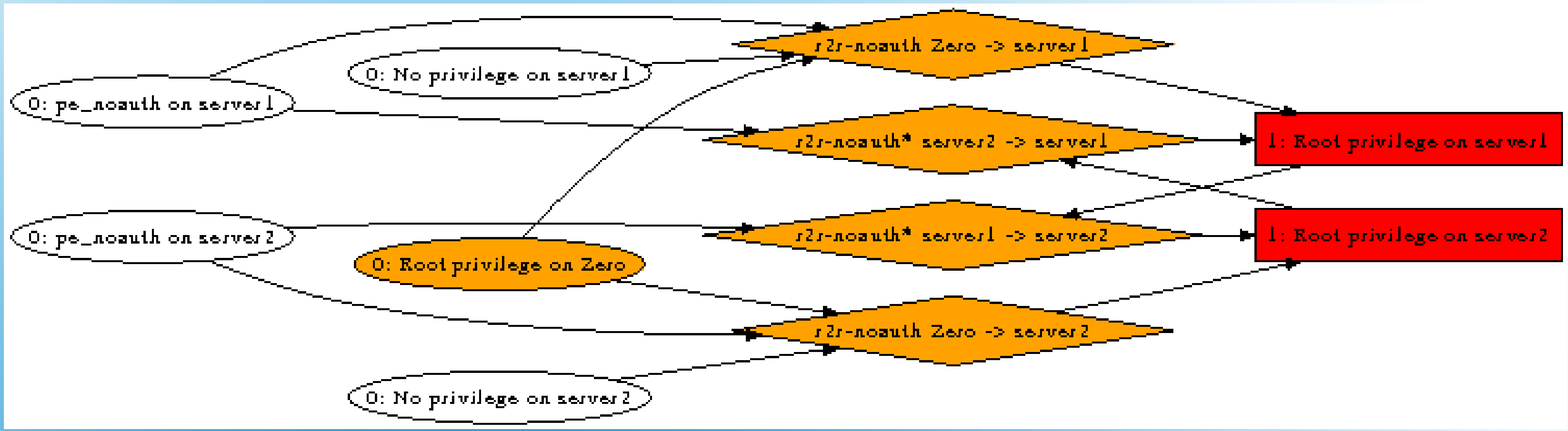
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Introduction
- Attack Graphs
  - Model
  - Creation
- Analysis of Attack Graphs
  - Evolutionary Method
  - Modes of Analysis
- Experimental Results

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Problem: Vulnerability scanners limited
    - Only evaluates individual machines
    - Cannot show how vulnerabilities relate
- Example: “Foothold” situation
    - Attacker compromises machine A
    - Machine A has private communication channel with machine B
    - Attacker uses machine A to attack machine B

- Solution: Attack graphs
  - Visual representation of exploits paths



- Benefits of analyzing attack graphs
  - Find a set of hardening measures
  - Perform “what if” evaluations
  - Assist with network design
  - Guide forensics evaluation
  - Detect multi-stage attacks from IDS alerts

Attack Graphs

Model

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Nodes of the graph
  - Initial nodes represent the present state of the network
  - Interior and terminal nodes represent states the attacker has achieved
- Edges of the graph
  - Attacks executed by attacker
  - Represented visually as a diamond “node”

- Exploit path is sequence from initial nodes to a terminal node
- Discovers exploit paths through attack template “requires/provides” syntax
  - Templates have preconditions (requirements) and postconditions (consequences)
  - Postcondition of one attack may be a precondition for another attack
  - Path is sequence of such relationships

SSH Attack Template

- Preconditions
  - Target has SSH vuln
  - Priv source >= user
  - Priv target < root
  - Source can connect to target on port 22
- Postcondition
  - Attacker has priv root on target

IIS Attack Template

- Preconditions
  - Target has IIS vuln
  - Priv source >= user
  - Priv target < root
  - Source can connect to target on port 80
- Postcondition
  - Attacker has priv root on target

- Abstract exploit templates eliminate most redundancy
- Currently models
  - Privilege escalation
  - Password guessing
  - Information leaks
  - Altering firewall and router rules

R2R Attack Template

- Preconditions
  - Target has R2R vuln
  - Priv source >= user
  - Priv target < root
  - Source can connect to target on port r2r
- Postcondition
  - Attacker has priv root on target

Attack Graphs

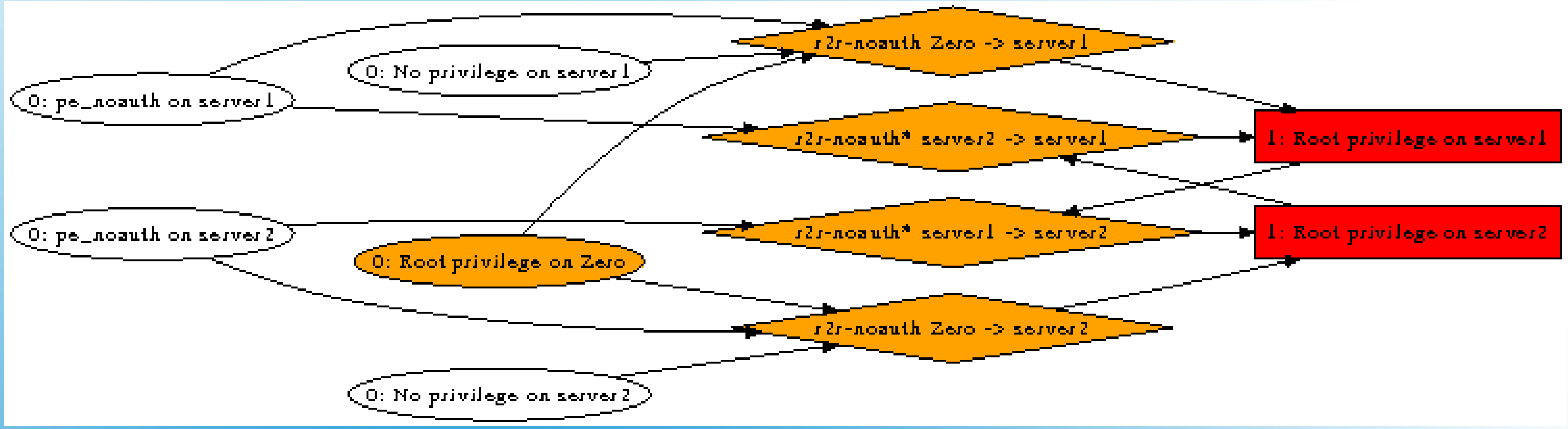
Generation

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Input data
  - List of vulnerabilities present on all machines
  - Model of firewall and router rules
- Attacker model
  - Assumes a single attacker for each graph
  - Initial privileges attacker has on all machines
  - Additional “attacker” machines
  - Can model insider and outsider scenarios

- Preprocessing
  - Convert all vulnerabilities and port numbers to abstract model
  - Cluster identical machines
    - Must have same vulnerabilities AND connectivity
    - Less work for the generator
- Generation
  - Use expert system to discover all possible exploit paths

- Outputs graph as data file and visualized graph



Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Visual complexity can rise quickly

Attack graph for network with 15 hosts:

Analysis of Attack Graphs

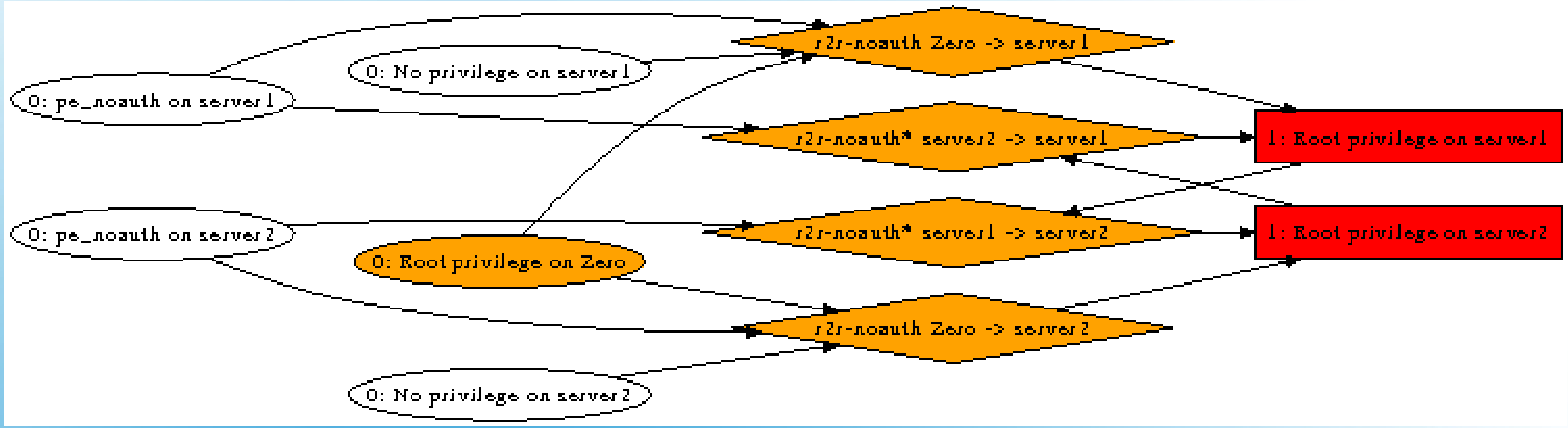
Evolutionary Method

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

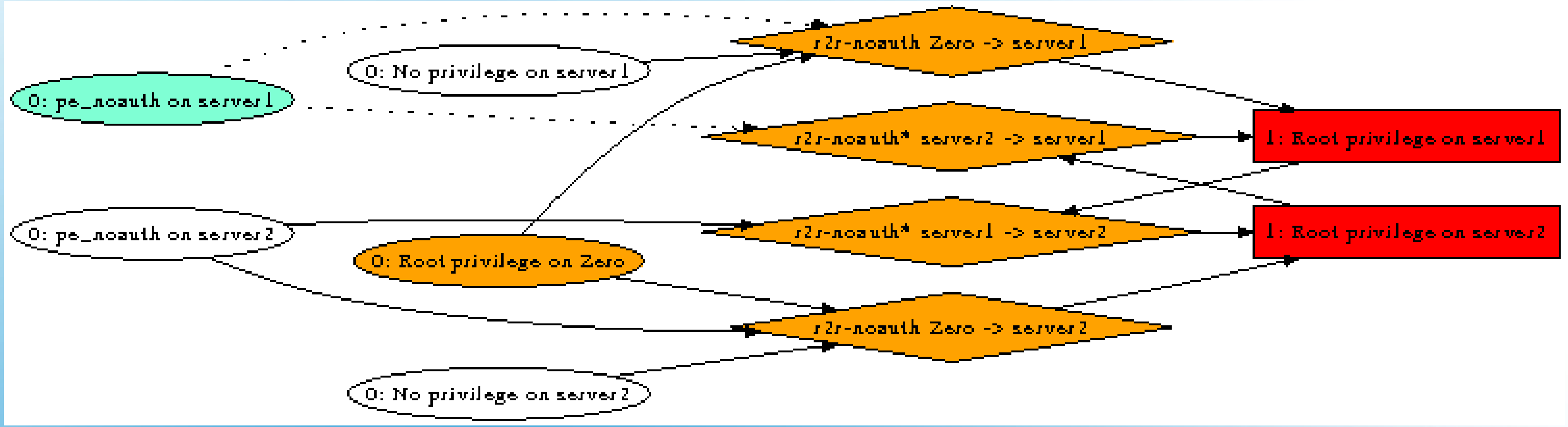
- Goal: Prevent attacker from achieving certain resources (“goal nodes”) in graph
- Evolutionary Method
  - Computationally infeasible to brute force
  - Start with random solutions
    - Solution varies with analysis mode
  - Use genetic algorithm to refine solutions
    - Guided search of solution space
  - Flexible and allows multiple solutions

- Example: Find a set of patches
  - Initial solutions are random subset of patches
  - Applies patches to graph and sees how well the patches disconnect the goal nodes
  - Assign a fitness metric
  - Select solutions with best fitness
  - “Breed” them to create next generation
  - Repeat

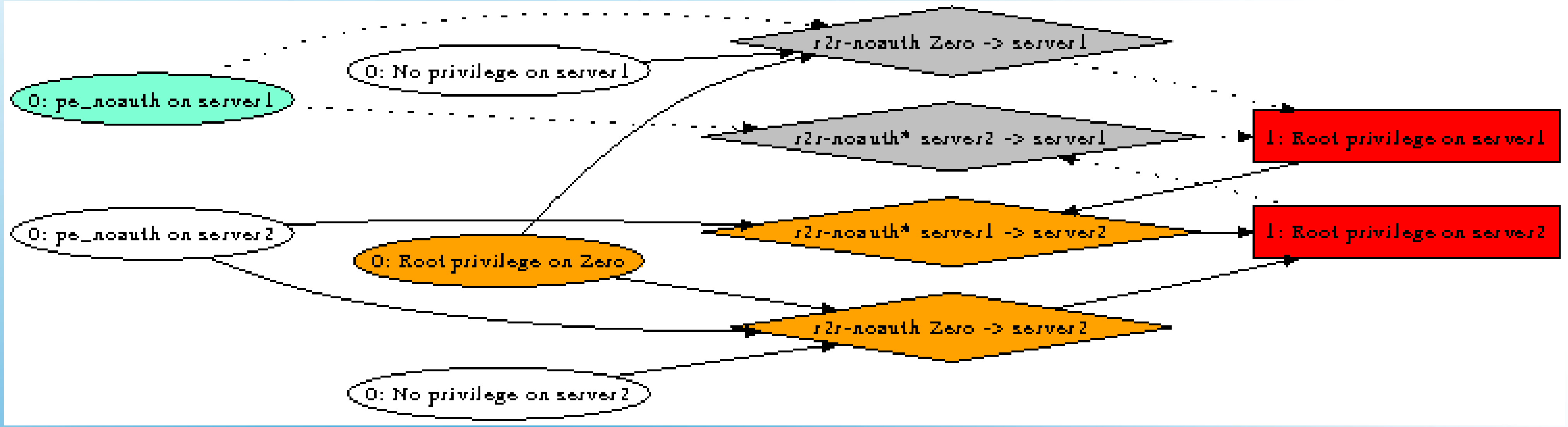
- Assessing fitness is most CPU intensive task
- Must apply each hardening measure and cascade its effects throughout the graph
- Over 60% of the single-threaded application CPU time was spent in this function
- Switched this task to multi-threaded function
  - Each has its own copy of the attack graph
  - Memory is cheap, time is not (usually)



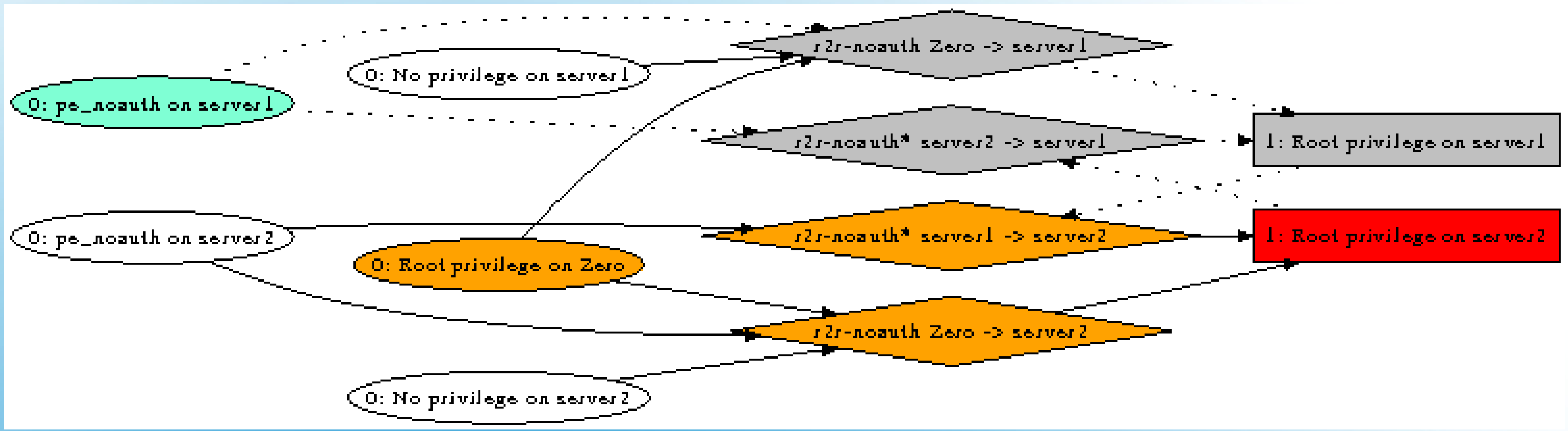
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield



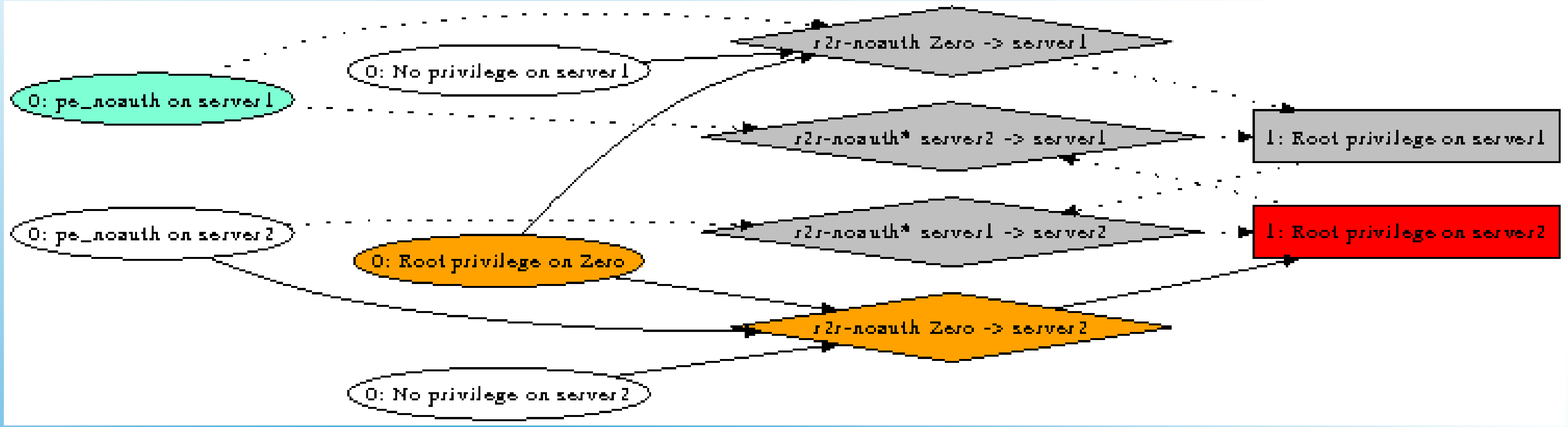
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield



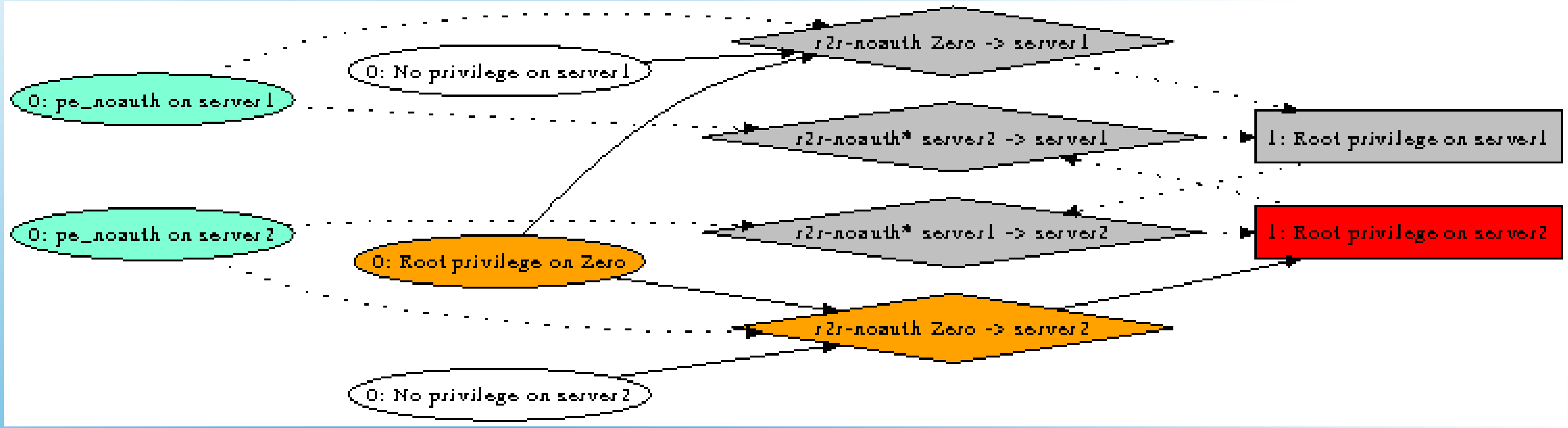
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield



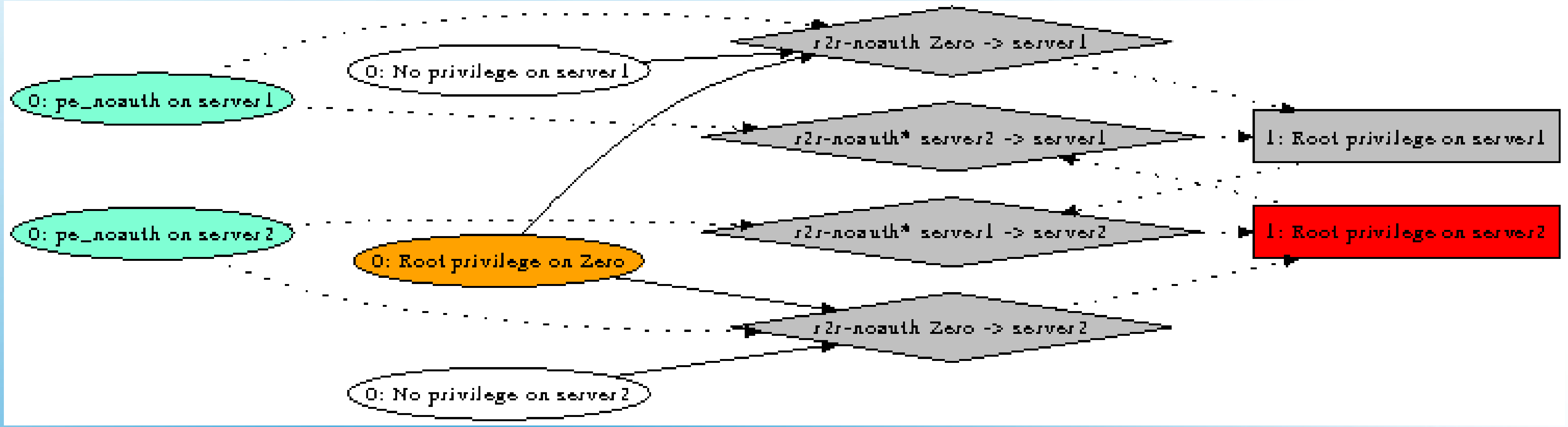
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield



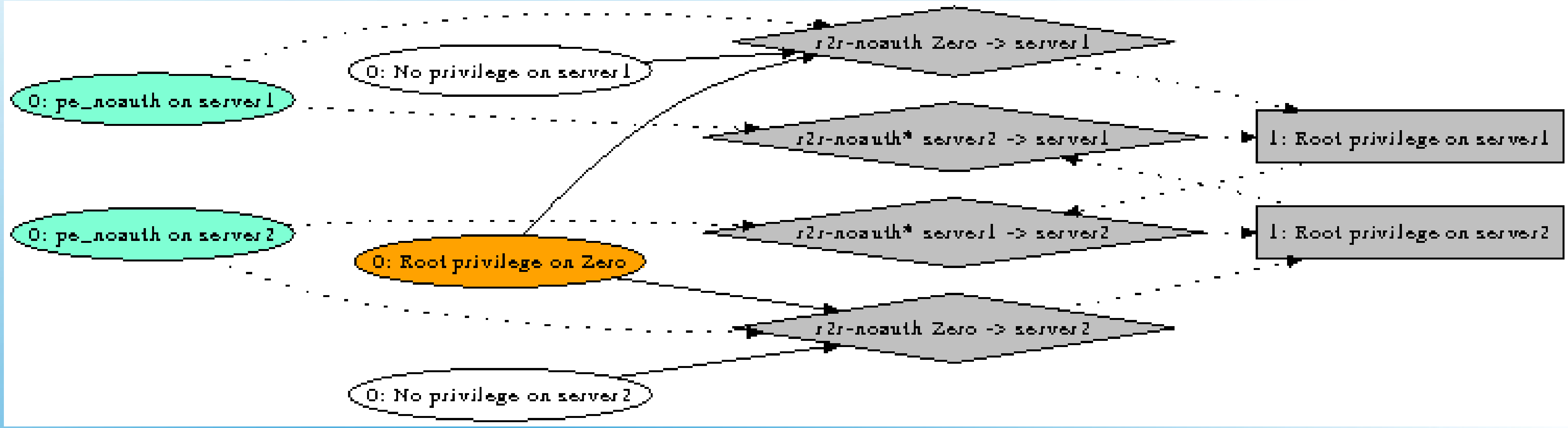
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield



Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield



Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield


r2r-noauth Zero -> server1
0: No privilege on server1
0: pe_noauth on server1
r2r-noauth* server2 -> server1
1: Root privilege on server1
0: pe_noauth on server2
r2r-noauth* server1 -> server2
1: Root privilege on server2
0: Root privilege on Zero
r2r-noauth Zero -> server2
0: No privilege on server2

- Fitness metric measures benefit of solution and cost of solution
  - Affected by mode of analysis and policy
- Policy model allows defaults specified by mode to be overridden
  - Can override both costs and benefits for specific cases or general cases
  - Can have a different policy for different modes of analysis

Analysis of Attack Graphs

Modes of Analysis

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Find set of hardening measures
  - Prevent attacker from reaching resources by patching machines, applying new firewall or router rules and/or placing IDS sensors
  - Can also be run in “patch only” mode
  - Solution is a proposed set of measures
  - Fitness metric based on cost for measures in set and how well they disconnect the attacker from the goal nodes

- Strategic Planning
  - Assess unknown risks by asking “what if”
  - Affects the generation of the attack graph
  - Alter the vulnerability list or firewall/router rules to reflect the scenario
  - Generate an attack graph for the scenario
  - Analyze resulting graph using any other mode

- Network Design – Simple mode
  - Administrator designs several different sets of firewall and/or router rules for the network
  - Attack graph is generated for each design
  - Risk metric is calculated based on how well connected the goal nodes are to the graph
  - Design with lowest risk metric is selected
- Simple mode is not very interesting
  - Just a variation on strategic planning

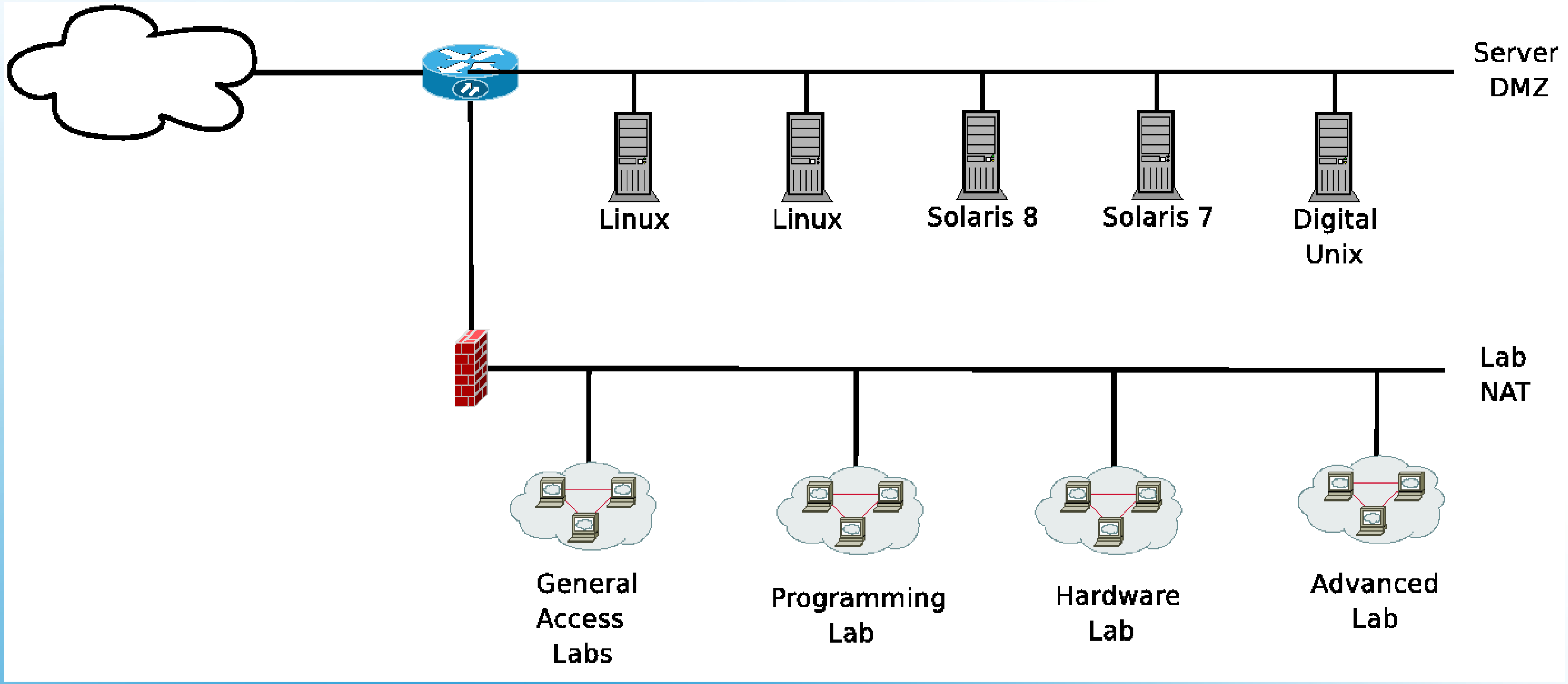
- Network Design – Evolutionary Mode
  - Administrator gives a single prototype design
  - Evolutionary analysis seeks improvements
  - Solutions alter firewall/router rules or place IDS sensors
  - Fitness metric based on how well goal nodes are disconnected or watched
  - Outputs several designs that minimize both risk and cost

- Forensic Evaluation and IDS Alerts
  - Match forensic evidence and/or IDS alerts to nodes in graph
  - Detect exploit paths in use by attacker
  - Forensic evaluation – Guides analyst by highlighting other resources the attacker may have compromised
  - IDS alerts – Integrate with intrusion response or activate additional monitoring

Experimental Results

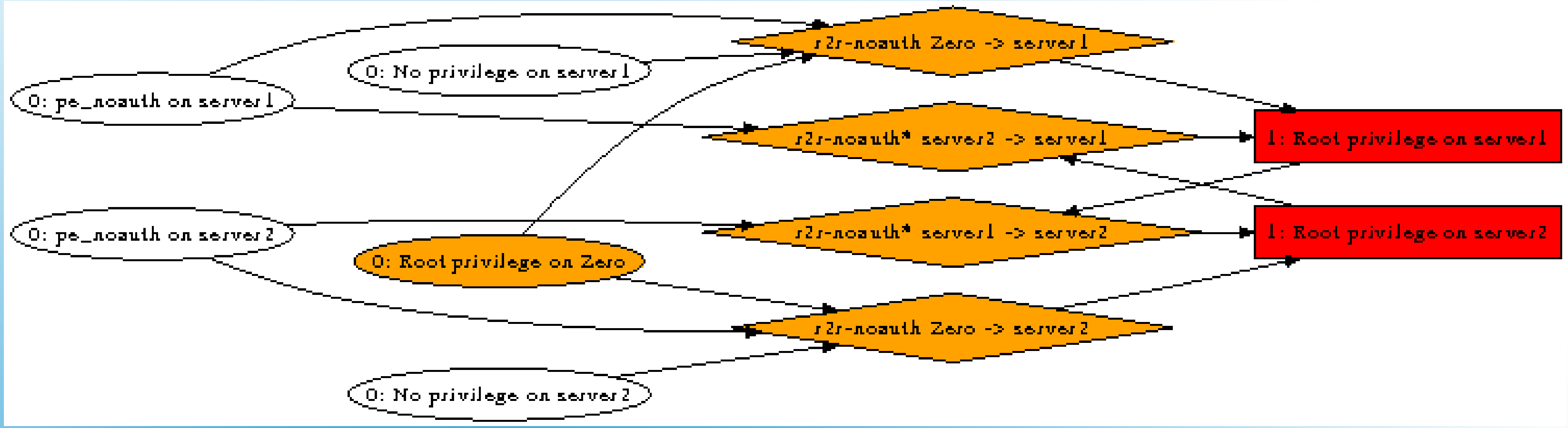
CSU Bakersfield
Computer Science Department
Instructional Laboratory Network

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield


Server
DMZ
Linux
Linux
Solaris 8
Solaris 7
Digital
Unix
Lab
NAT
General
Access
Labs
Programming
Lab
Hardware
Lab
Advanced
Lab

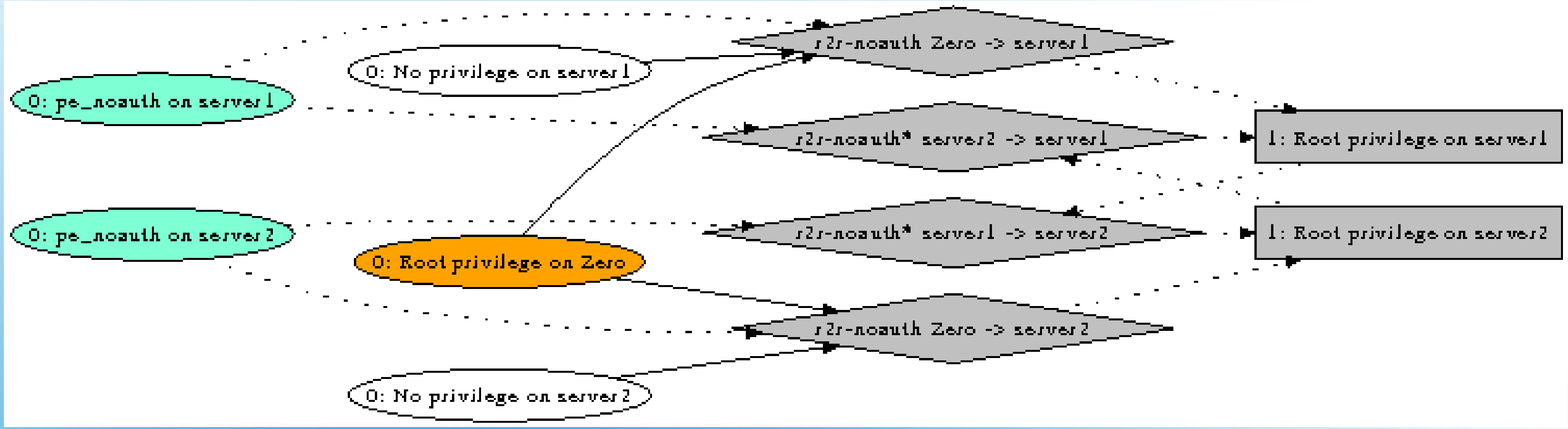
- Base Configuration Scenario
  - Attacker is an outsider
- Strategic Planning Scenarios
  - Student visits a malicious website with a vulnerable version of Firefox
  - A malicious student attacks the network from one of the instructional lab machines
  - An instructor brings in a compromised laptop and plugs it into the LAN

- Base Configuration Original Graph



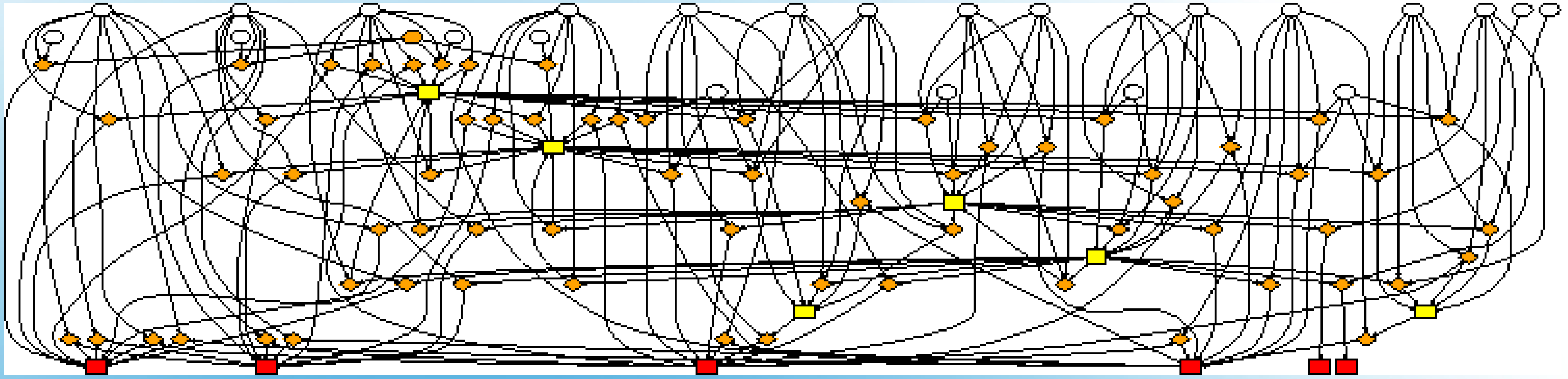
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Base Configuration Patched Graph



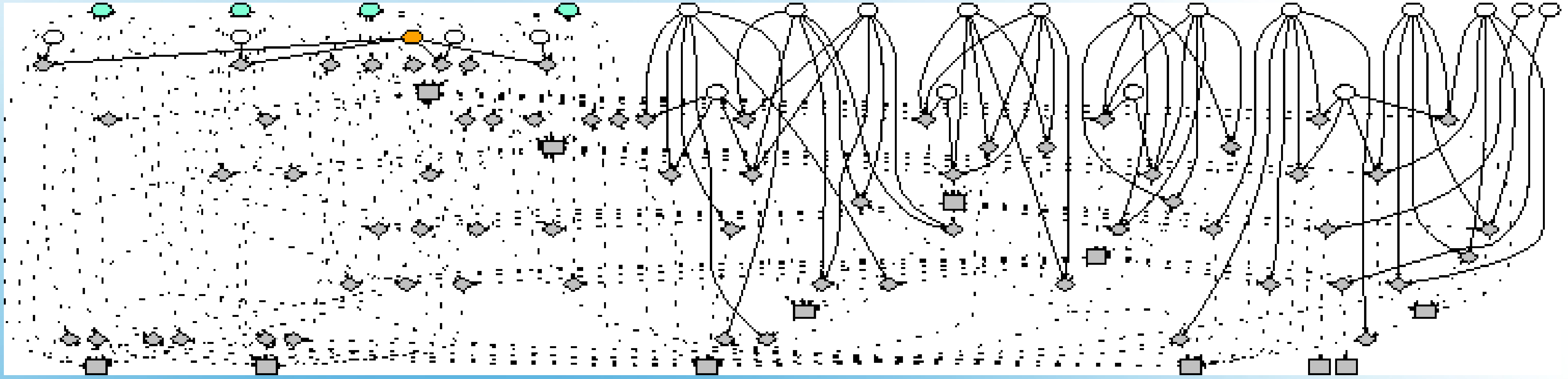
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Vulnerable Browser Original Graph

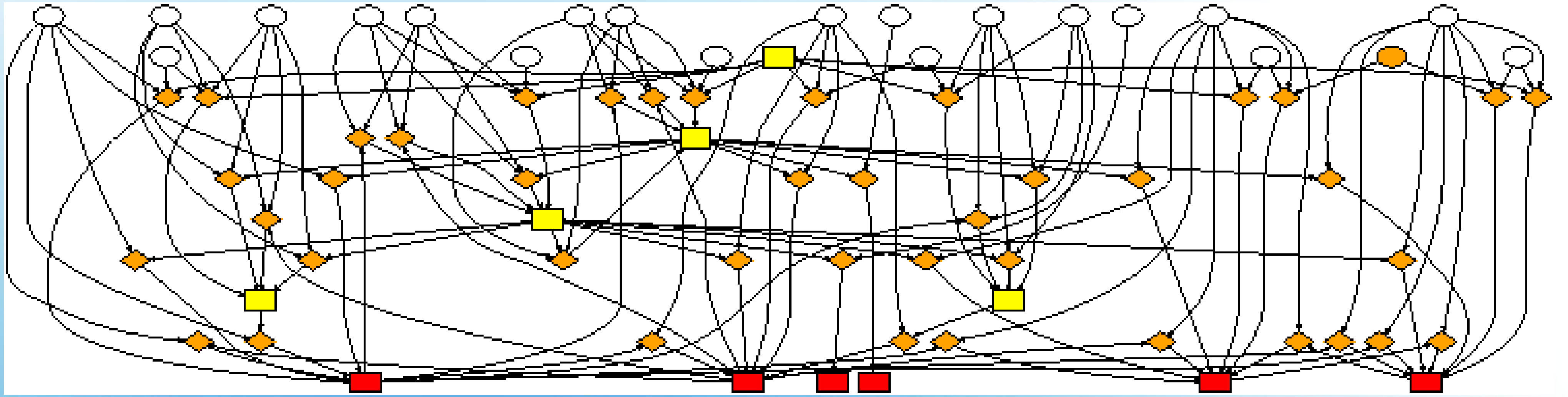


Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Vulnerable Browser Patched Graph

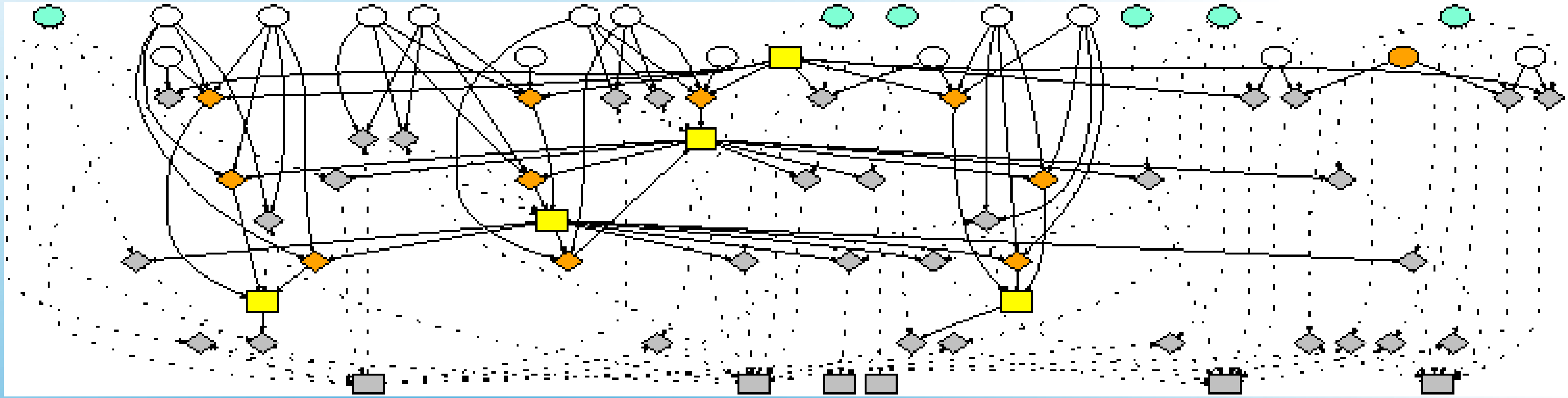


- Malicious Student Original Graph



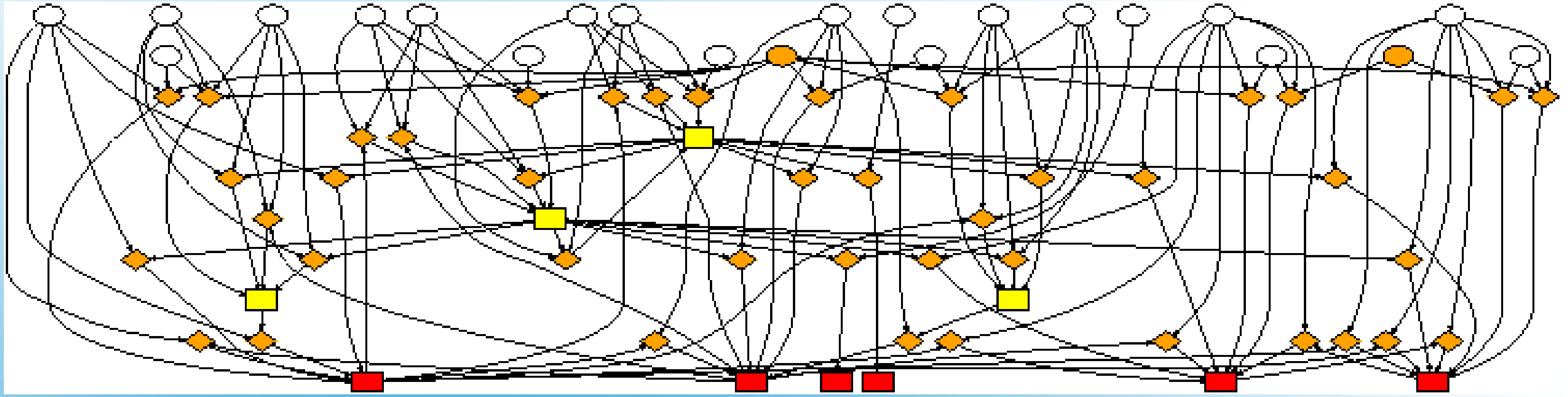
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Malicious Student Patched Graph



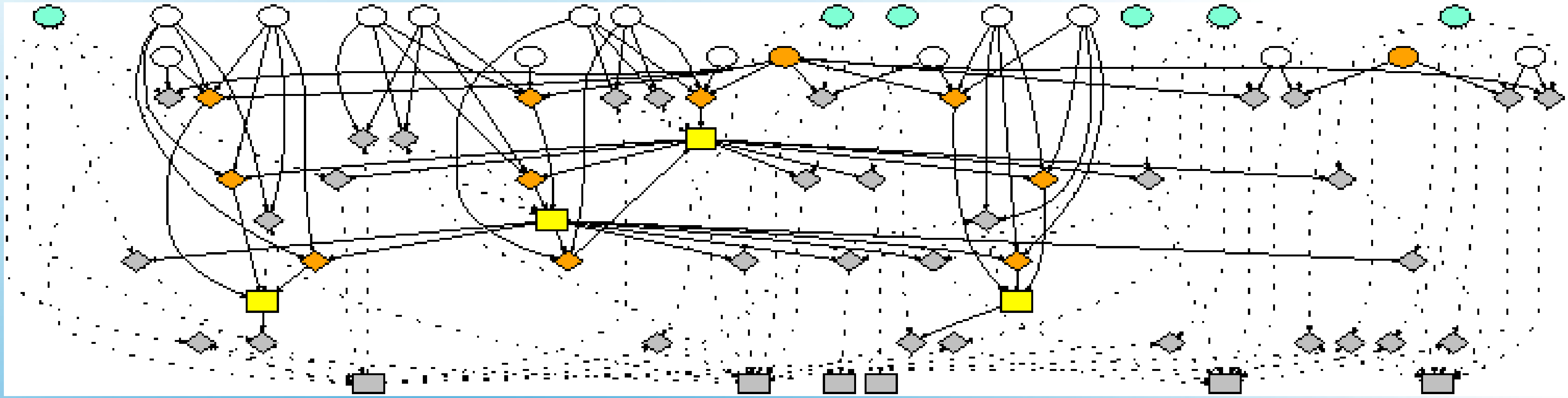
Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Rogue Laptop Original Graph

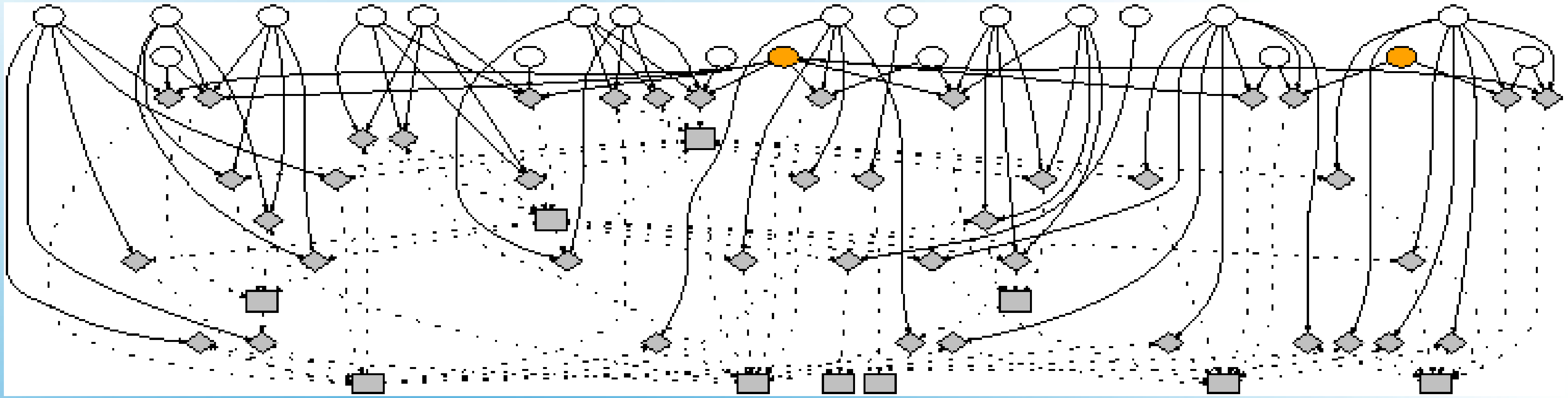


Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

- Rogue Laptop Patched Graph



- Rogue Laptop Redesigned Network Graph



- Scalability Testing
  - Generated networks with 5 to 2500 machines
  - Largest network took 1.5 hours to analyze on a quad-core Xeon 2.33GHz system
  - Smallest network took approximately 1 second
  - Larger networks have more complex attack graphs, so they take longer to analyze even with clustering and abstract exploit templates

Future Work

- Automate remaining “by hand” processes
  - Importing firewall and router rules
  - Translating Nessus plugin IDs to abstract exploit class names
- Allow multiple attacks in attacker model
- Implement IDS correlation mode
- Improve visualization of the graphs
- Create a cohessive GUI to tie all parts together

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield

Questions?

Students on this project:
Jonathan Berling
Fred McHale
John Millikin
Nick Toothman

Dr. Melissa Danforth
Department of Computer Science
California State University, Bakersfield