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FOUNDATIONS OF RESILIENT CYBER-PHYSICAL SYSTEMS

A Dynamic Control Scheme for the Secure Operation of Cyber-physical Systems

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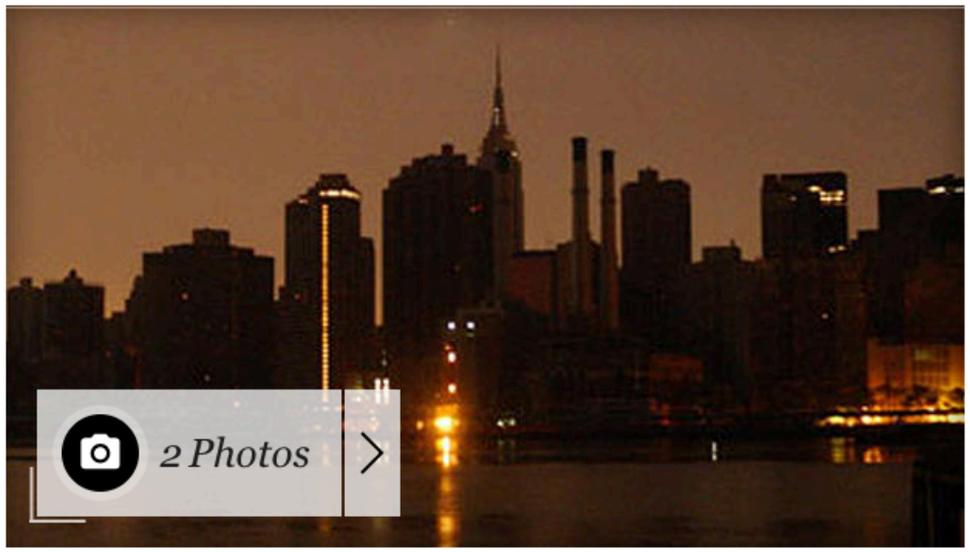
By **JAIME HOLGUIN** / **CBS/AP** / *August 15, 2003, 7:20 AM*

Biggest blackout in U.S. history



The dark Manhattan skyline, seen from Queens, is silhouetted against a pre-dawn sky Aug. 15, 2003. A widespread power outage hit most of northeastern United States Aug. 14, leaving the city in the dark. / **AP**

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Power is coming back to some of the 50 million people affected by the blackout which hit Thursday, continued into Friday, and is the biggest power outage in U.S. history.

The outage affected a wide swath of territory in the U.S. and Canada - including New York City, Albany, Hartford, Toronto, Ottawa, Detroit, Cleveland and Ontario

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Obama and the 2008 general election


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Delta Warns of Chaos After Power Outage, Worldwide System Failure

by ALASTAIR JAMIESON, SHAMAR WALTERS, KURT CHIRBAS and GABE GUTIERREZ

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Delta flights grounded worldwide due to computer outage
1:26

Tens of thousands of Delta passengers around the world were stranded Monday after a power outage at its Atlanta headquarters caused a global computer failure that halted all flights.

Check-in systems, airport screens and even the airline's website and smartphone apps were affected by the meltdown, which began at 2:38 a.m. ET and lasted six hours.

The airline suspended departures, with airport agents writing out boarding passes by hand. "Our systems are down everywhere," it told customers on Twitter.

Related: After the Glitch: What to Do if You're Flying Delta This Week

The outage ended at about 8:30 a.m. ET, with "limited" resumption of flights. By 1:30 p.m. ET, some 451 flights had been canceled and less than 1,700 of its 6,000 scheduled flights were in operation, the airline said.

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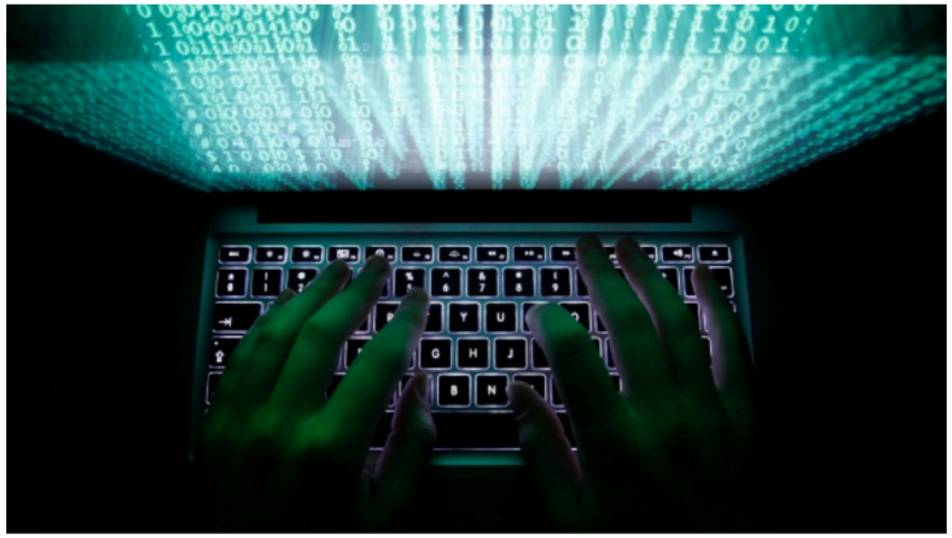
Hackers used 'internet of things' devices to cause Friday's massive DDoS cyberattack

Hackers say the attacks, which affected major sites like Twitter, Netflix and PayPal, were just a dry run

The Associated Press Posted: Oct 22, 2016 3:52 PM ET | Last Updated: Oct 22, 2016 4:15 PM ET



Friday's DDoS attackers now have a secret weapon in the increasing array of internet-enabled household devices they can subvert and use to wreak havoc. (Kacper Pempel/Reuters)

Facebook
Twitter
Reddit

Could millions of connected cameras, thermostats and kids' toys bring the internet to its knees? It's beginning to look that way.

On Friday, epic cyberattacks crippled a major internet firm, repeatedly disrupting the availability of popular websites across North America and Europe such as Twitter, Netflix and PayPal.

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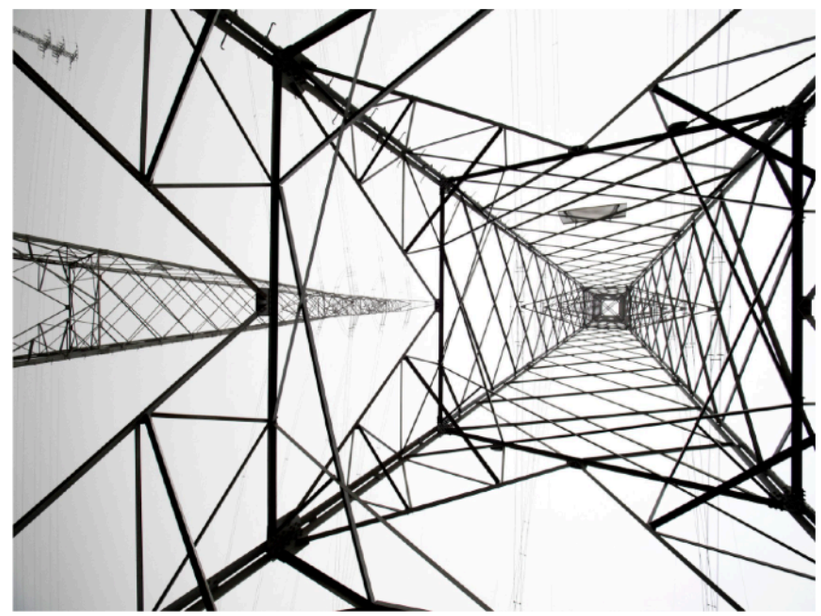
INSIDE THE CUNNING, UNPRECEDENTED HACK OF UKRAINE'S POWER GRID



JOSE A. BERNAT BACET/GETTY IMAGES

IT WAS 3:30 p.m. last December 23, and residents of the Ivano-Frankivsk region of Western Ukraine were preparing to end their workday and head home through the cold winter streets. Inside the Prykarpattyaoblenergo control center, which distributes power to the region's residents, operators too were nearing the end of their shift. But just as one worker was organizing papers at his

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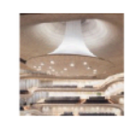

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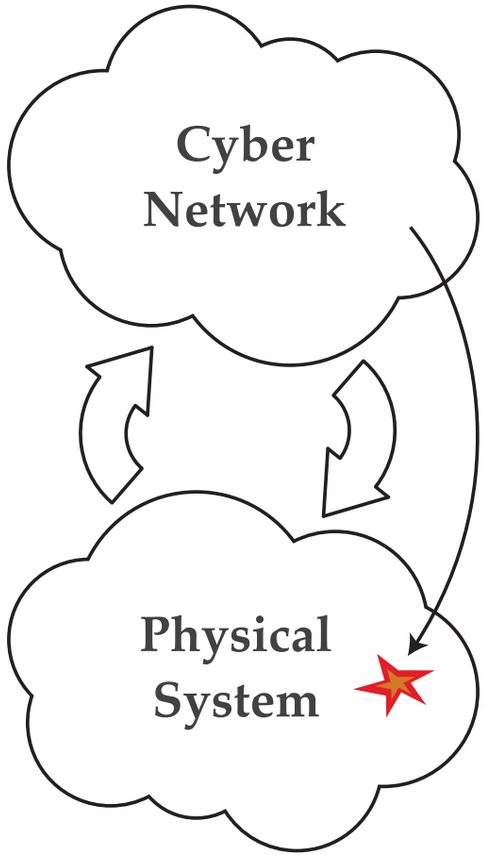
Objective

- We propose a model for the ***graceful degradation*** of **cyber-physical systems** while subject to persistent attacks from an adversary

We are interested in modeling, and defending against, **cyber attacks that trigger physical contingencies.**



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Cyber-physical Systems

1. **Cyber network**
   - Forms the computational, comm., and control structure of the system
2. **Physical infrastructure**
   - Represents the physical network of connections, switches, and sensors
   - Dynamics of the (continuous) **physical state** x_t are dictated by laws of nature

tightly integrated at all time-scales and levels

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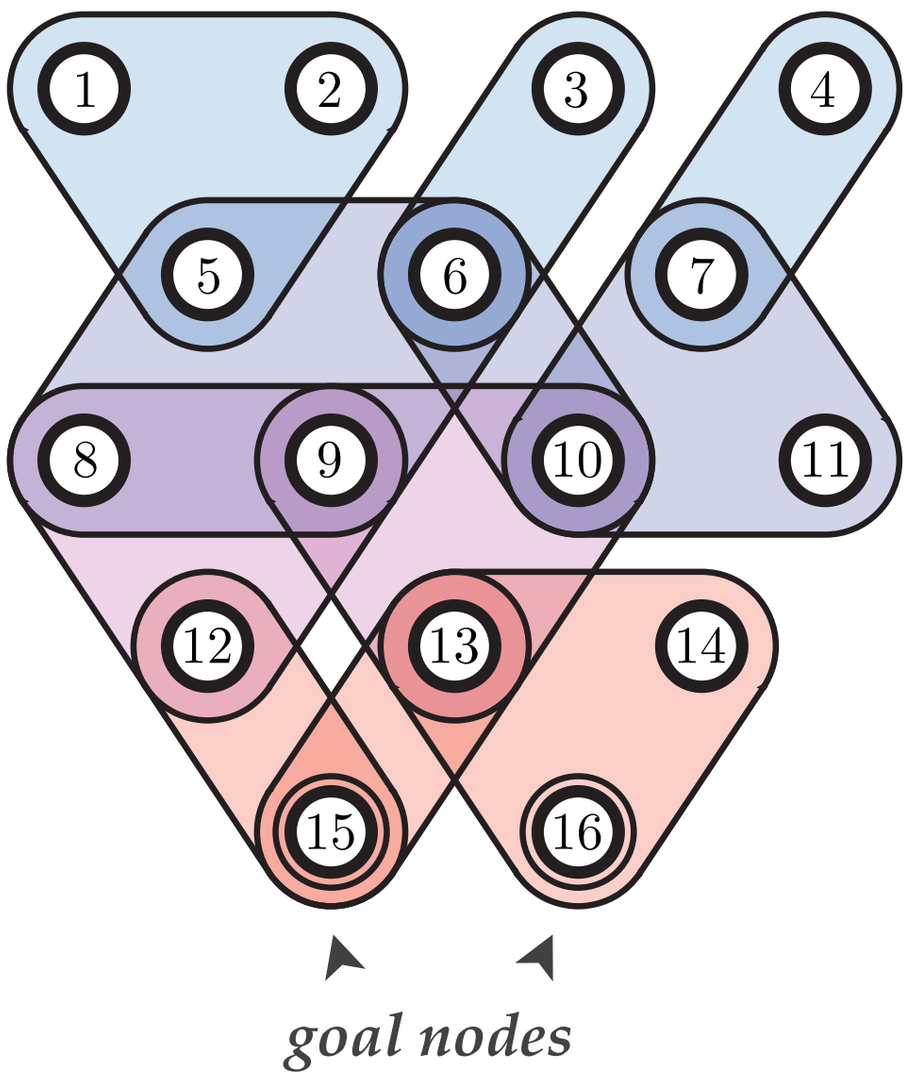
Cyber Layer



- Attacks are modeled using a dependency graph
  - **Nodes:** attacker capabilities
  - **Edges:** exploits

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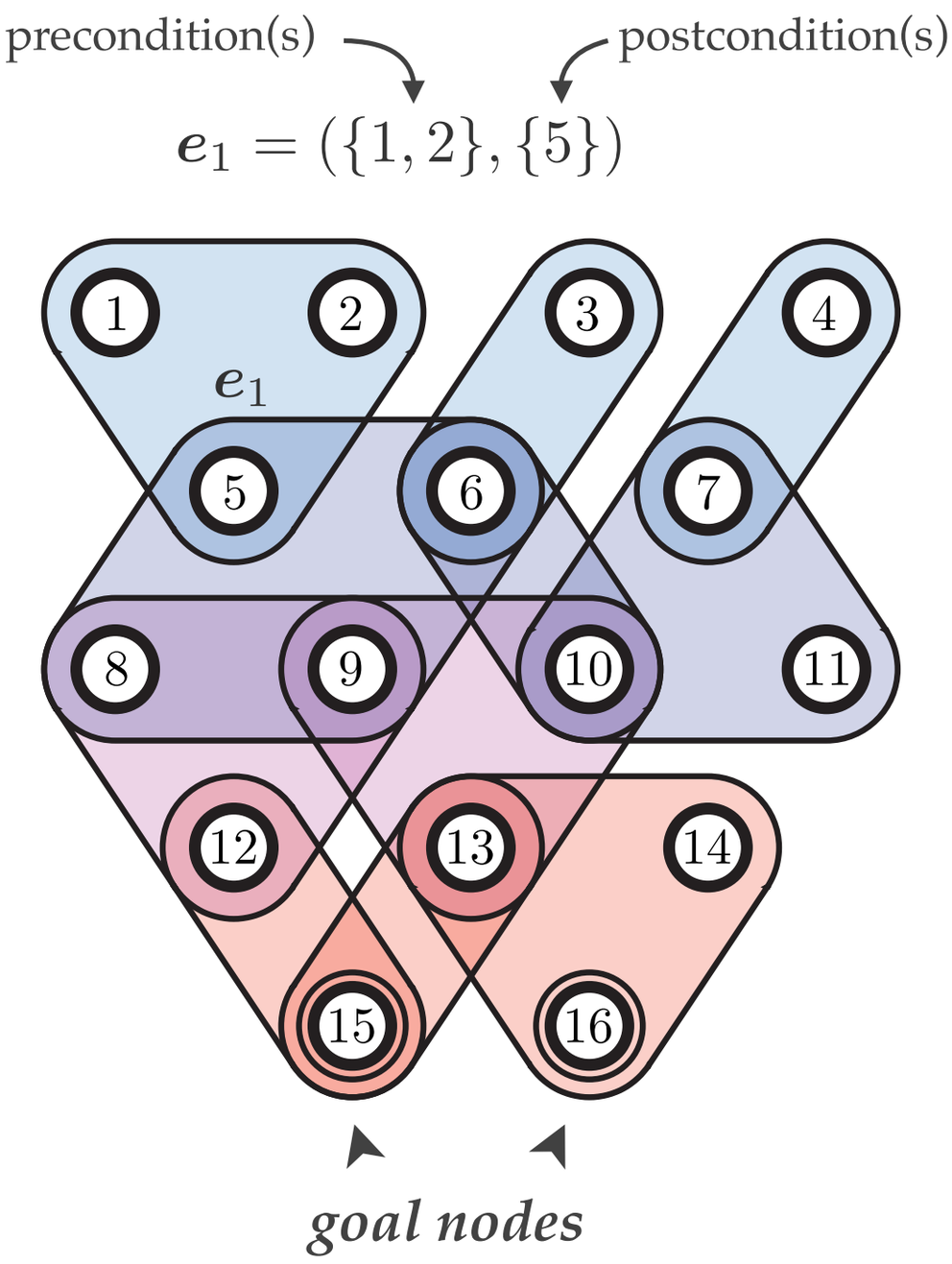

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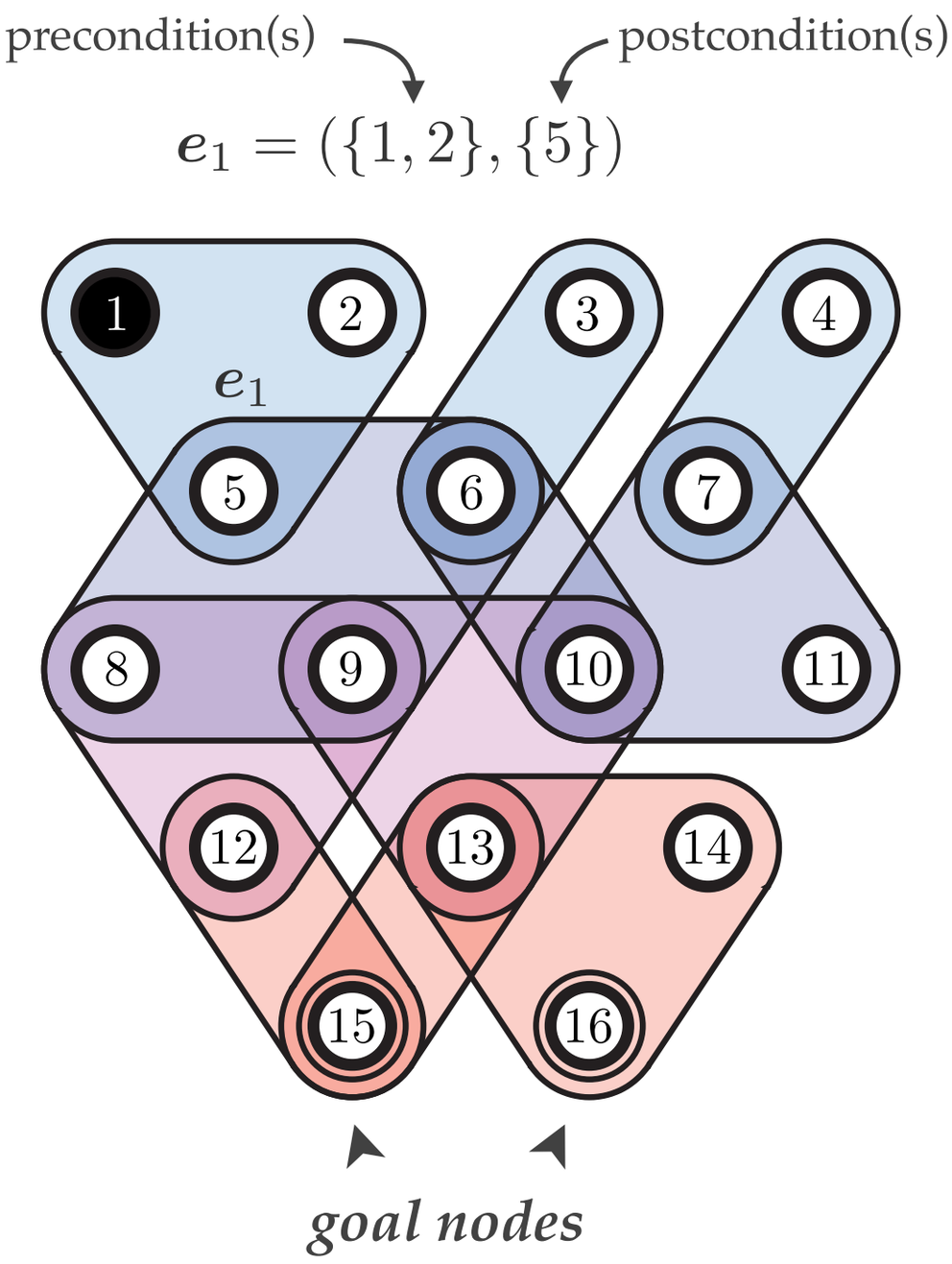

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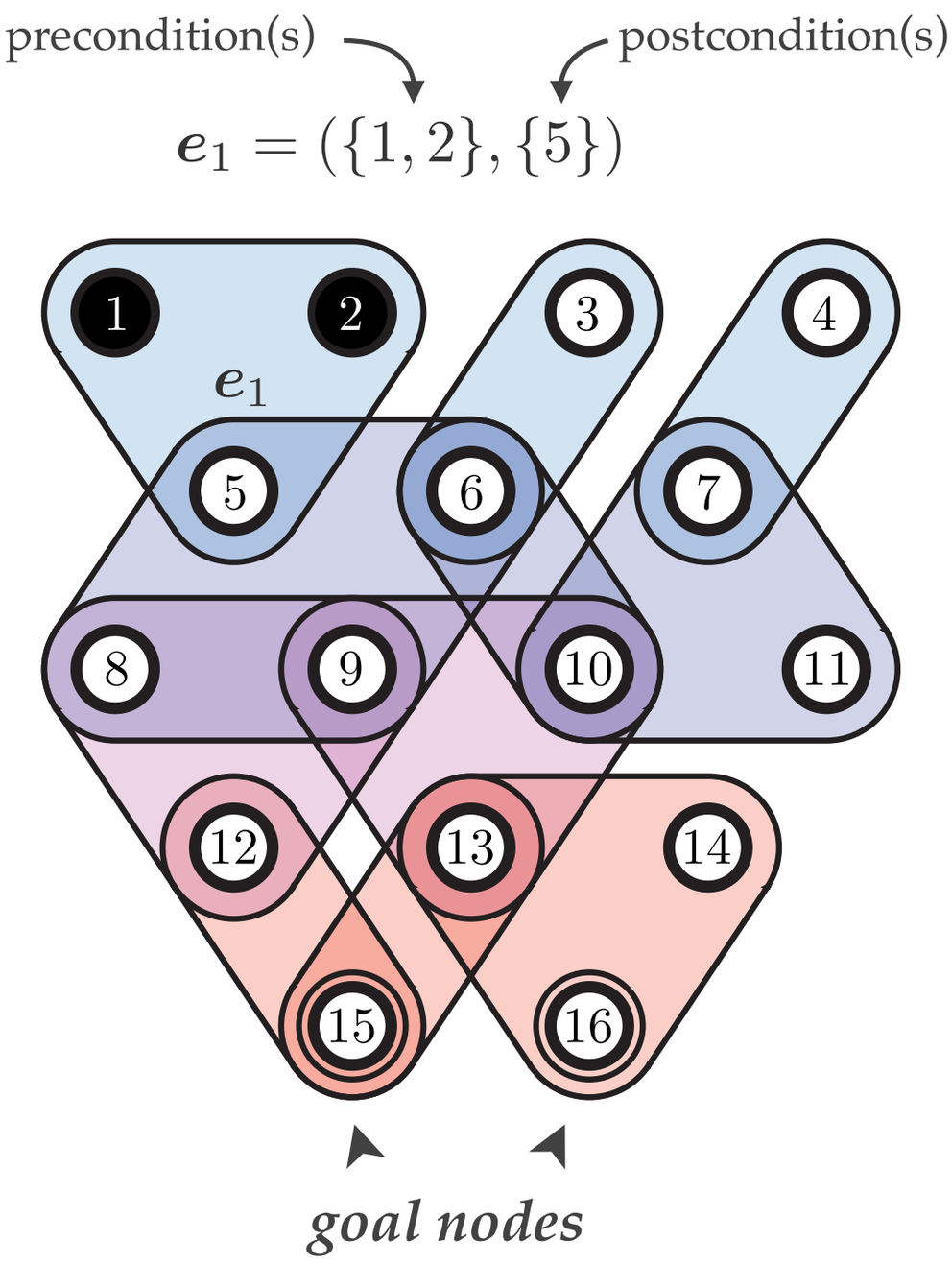

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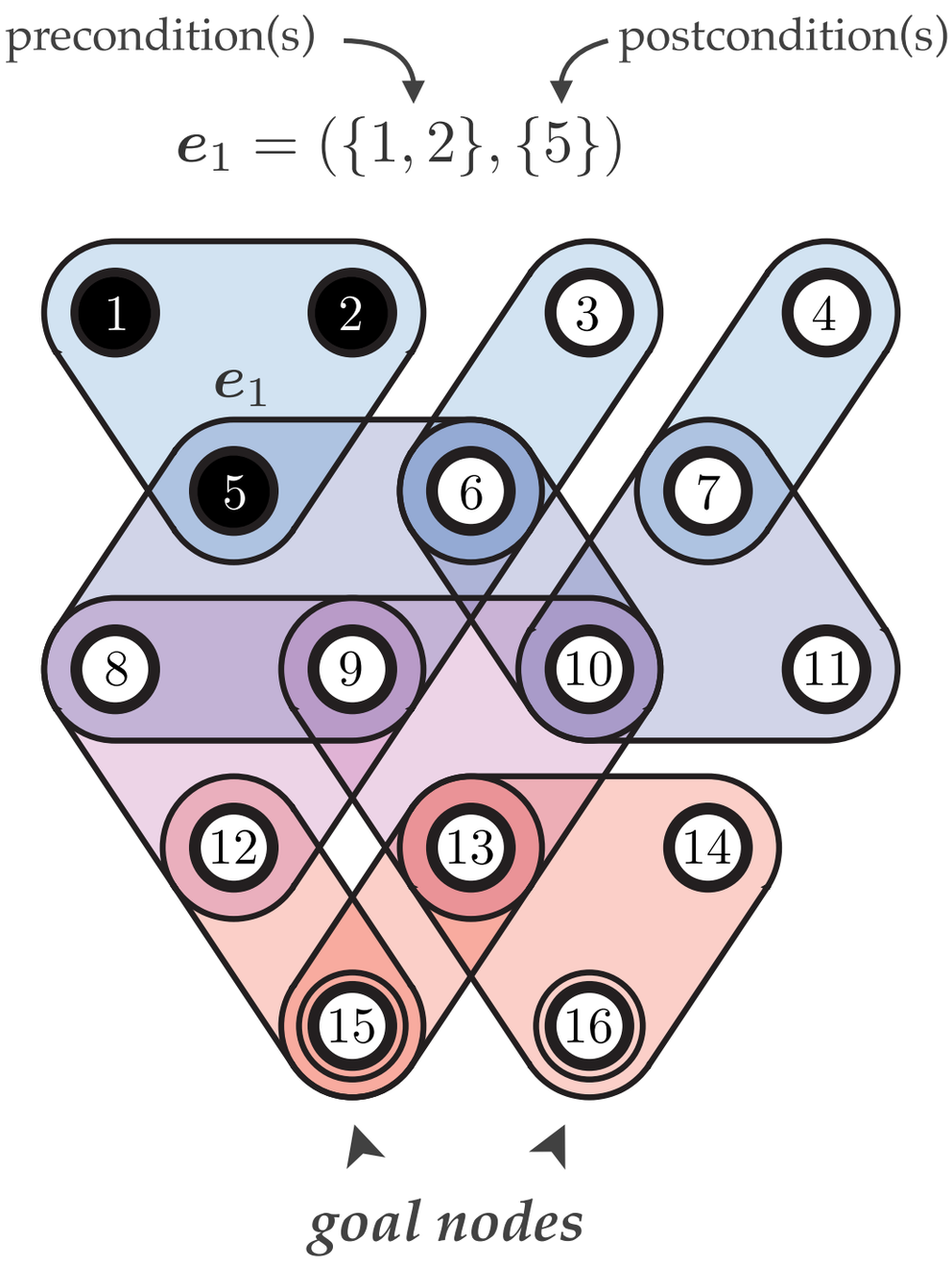

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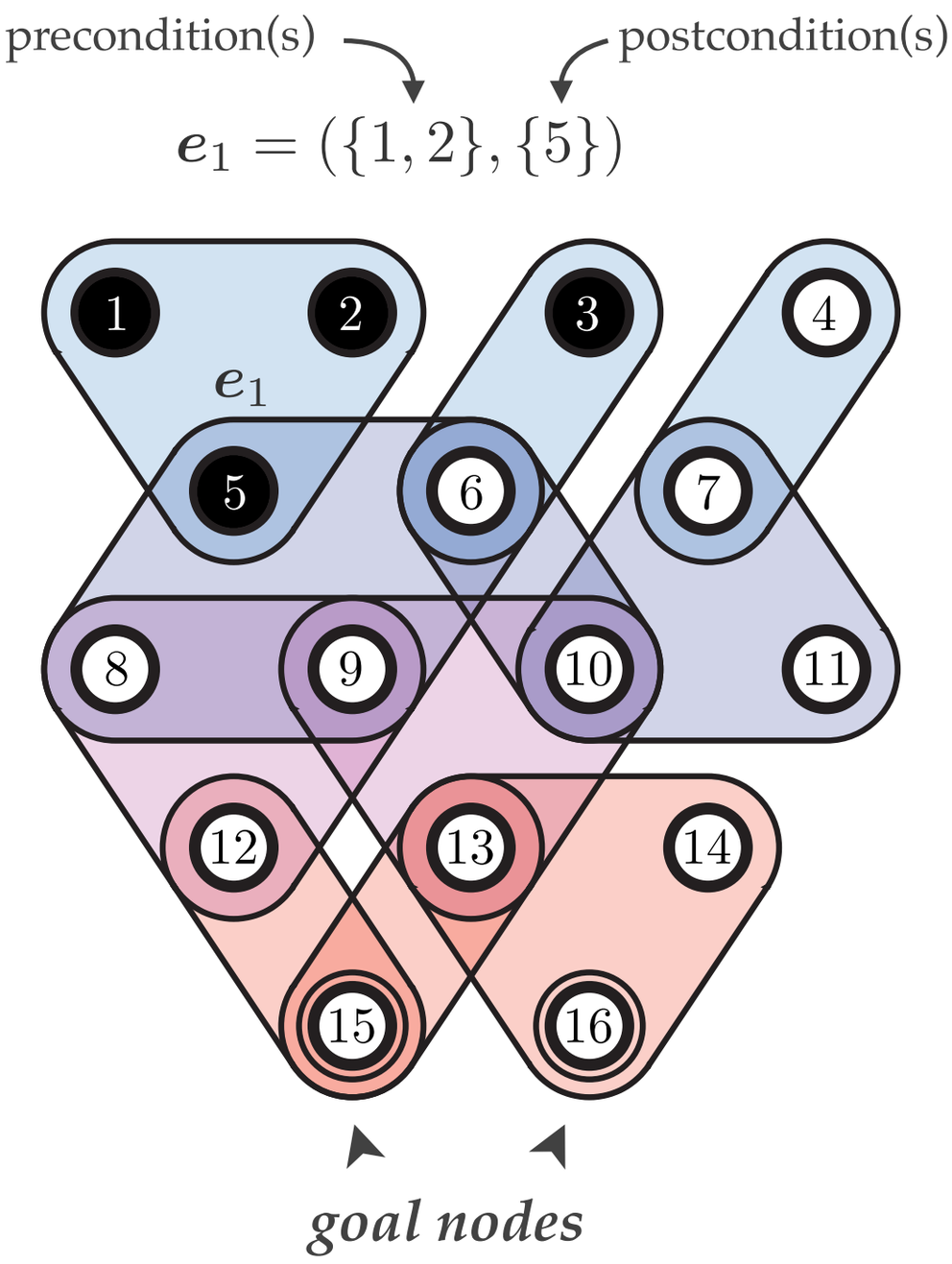

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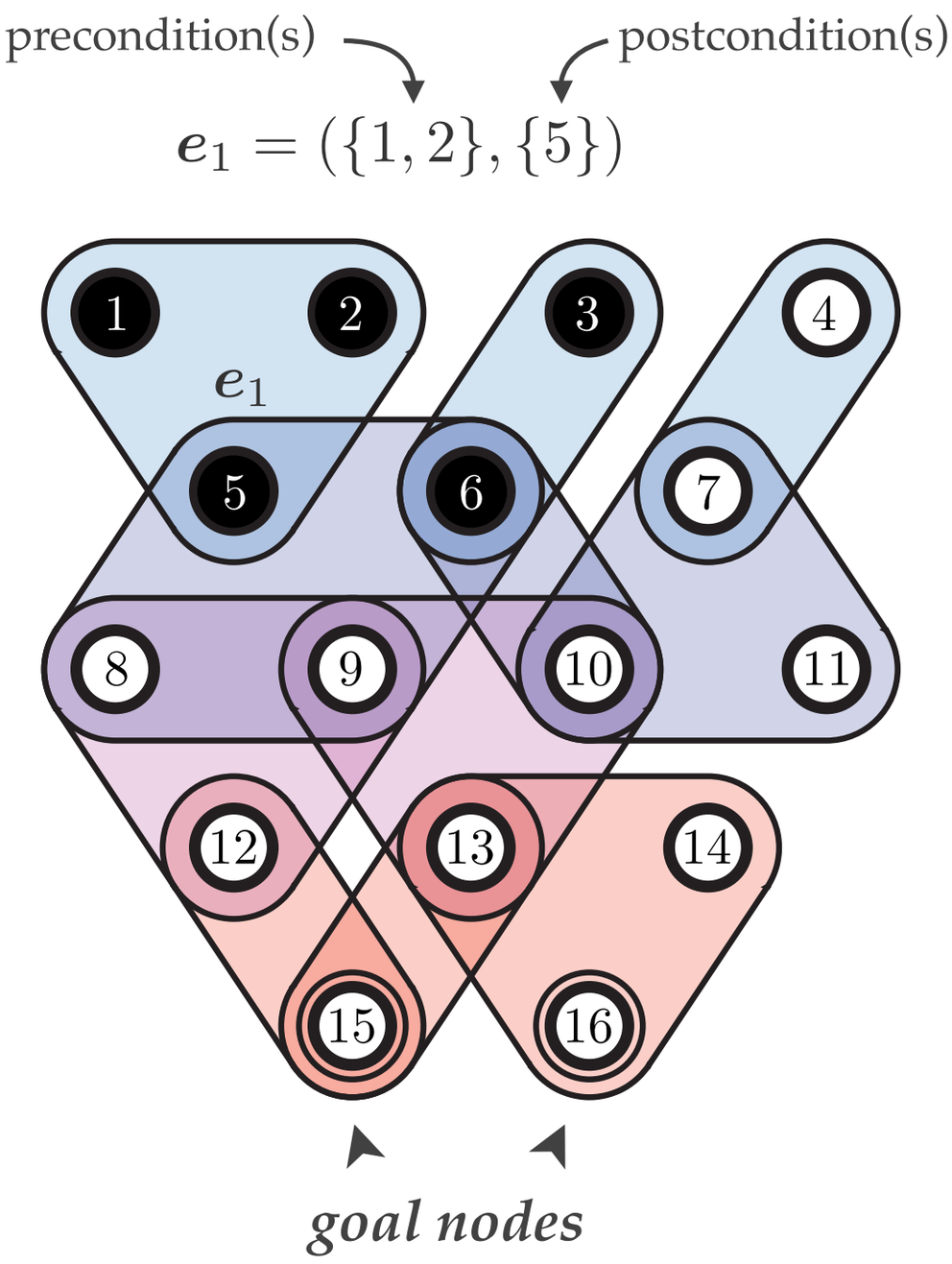

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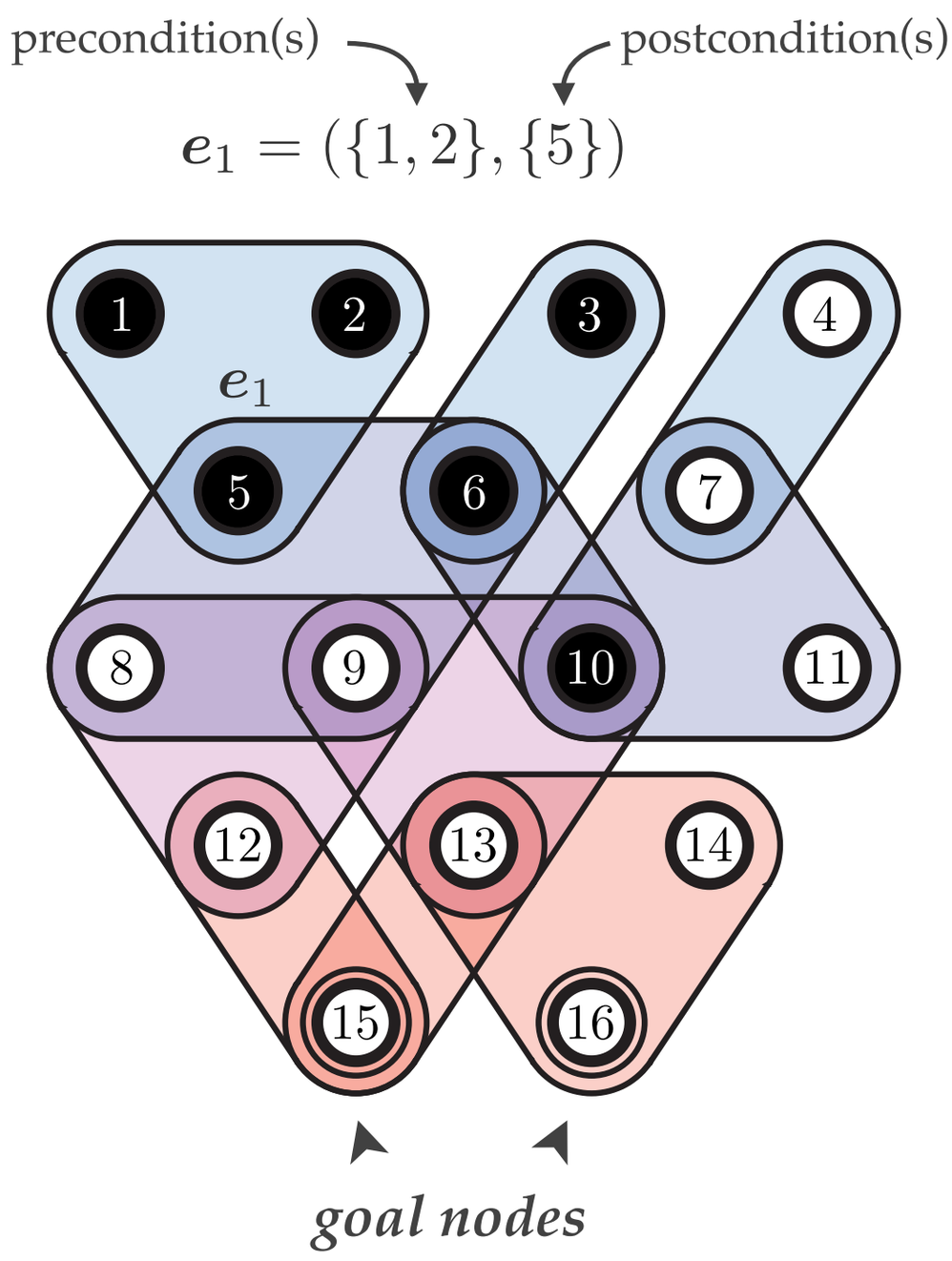

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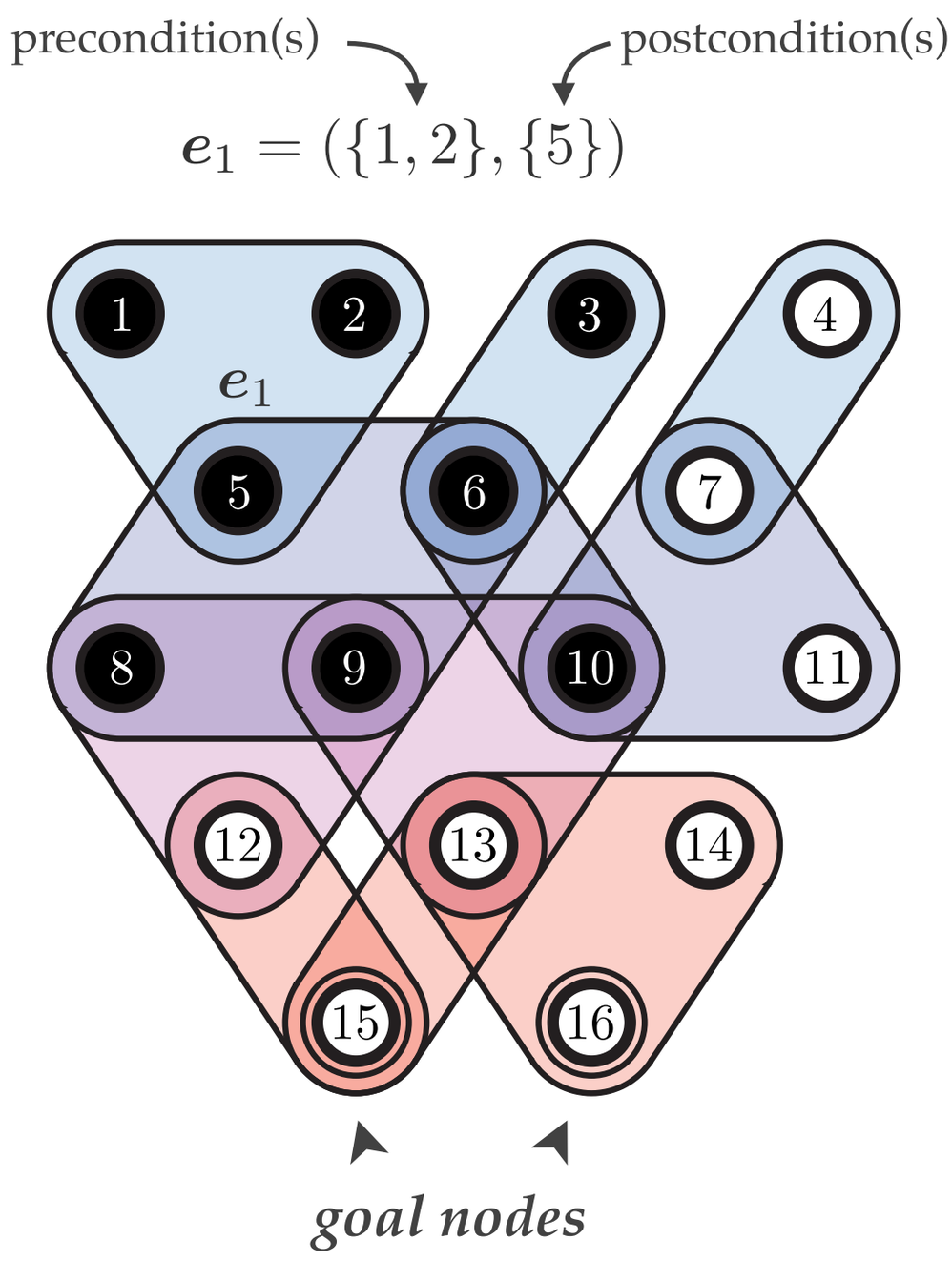

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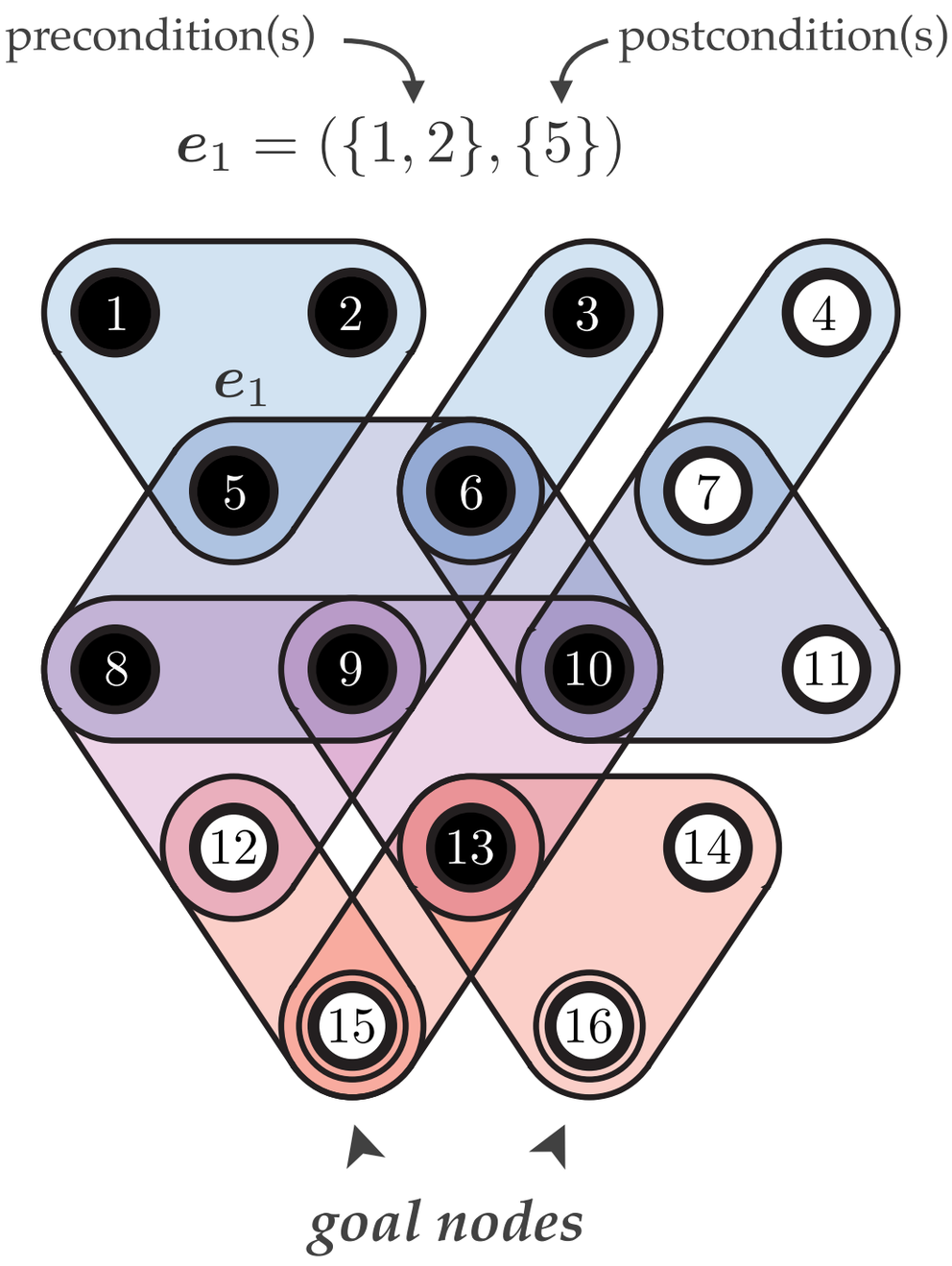

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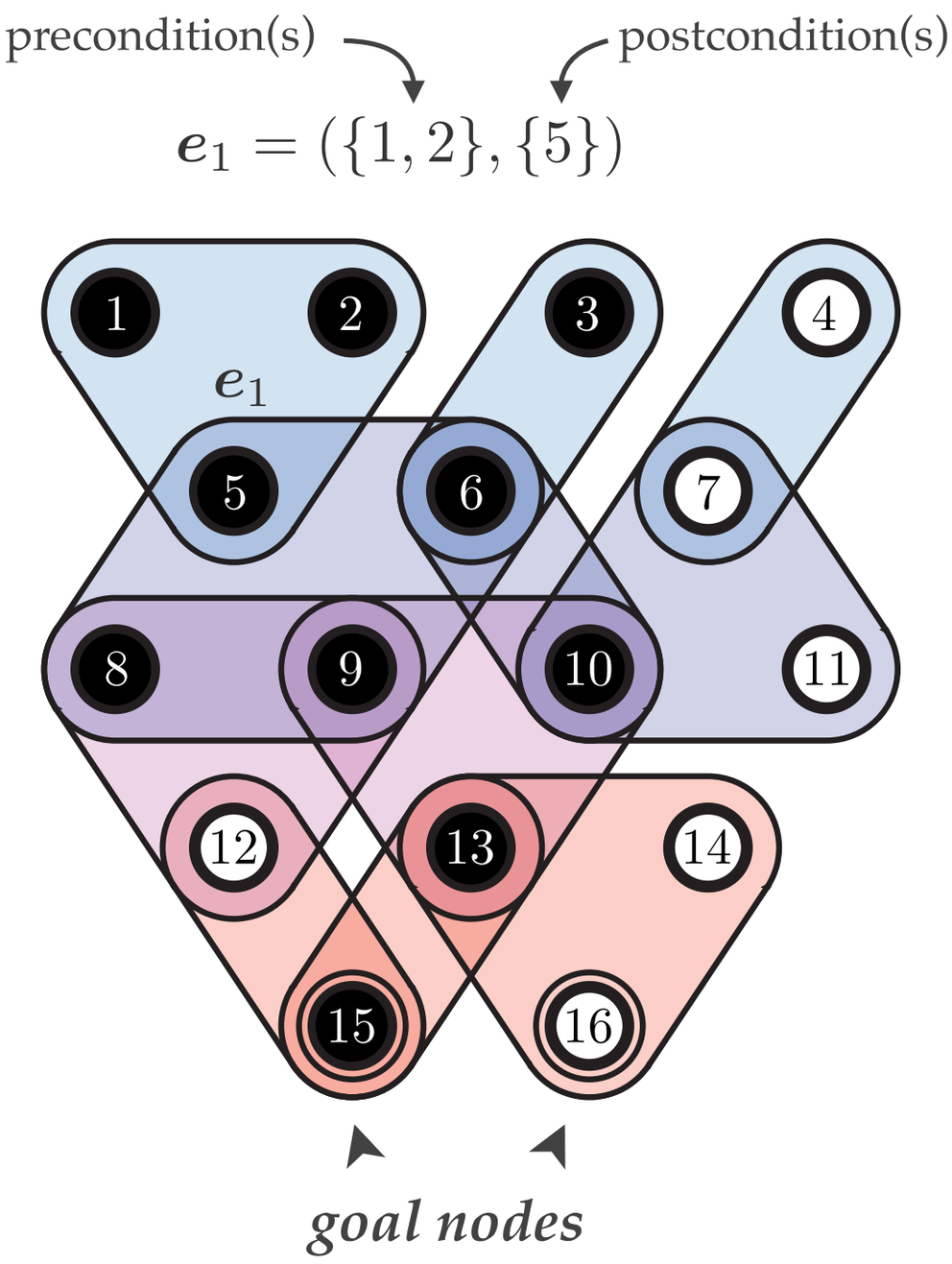

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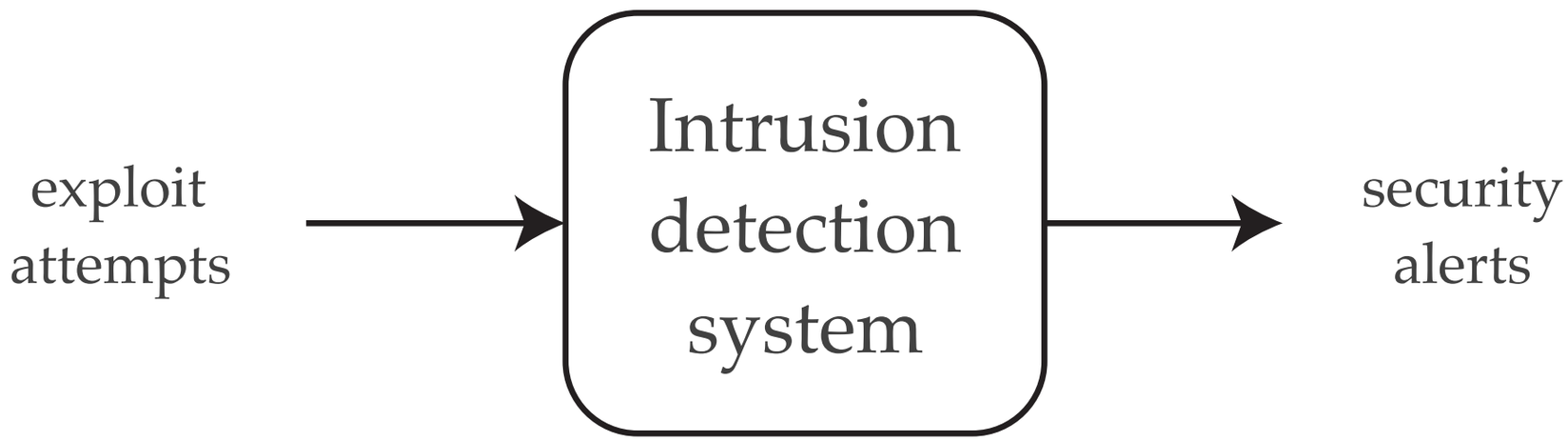
Defender's Information

- The defender does not know the **security state,** s_t, with certainty

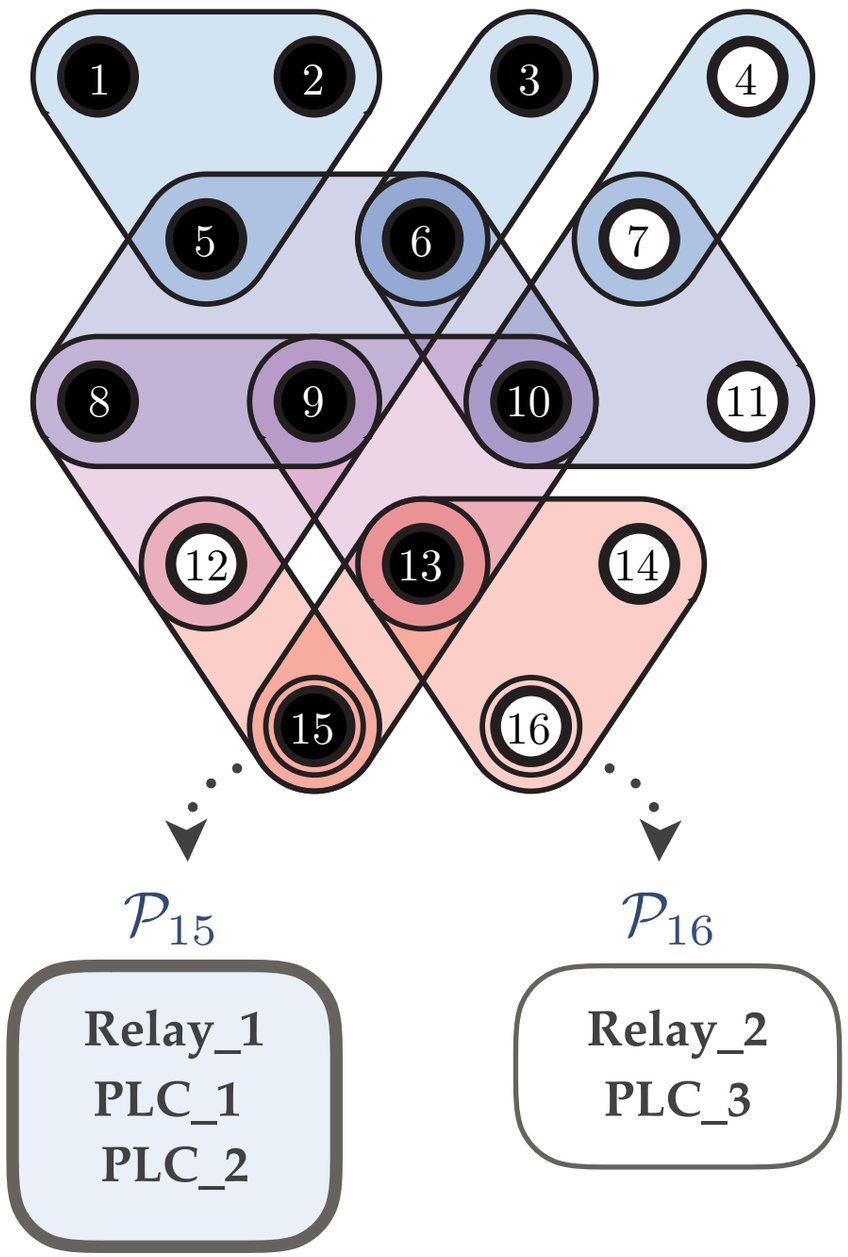


- Furthermore, the defender must estimate the **physical state,** x_t, using data from sensors

Goal Nodes

- Enabled goal conditions give the attacker **physical capabilities**

$\mathcal{P}_i$: **physical elements that the attacker can influence from i**



Goal Nodes

- Enabled goal conditions give the attacker **physical capabilities**

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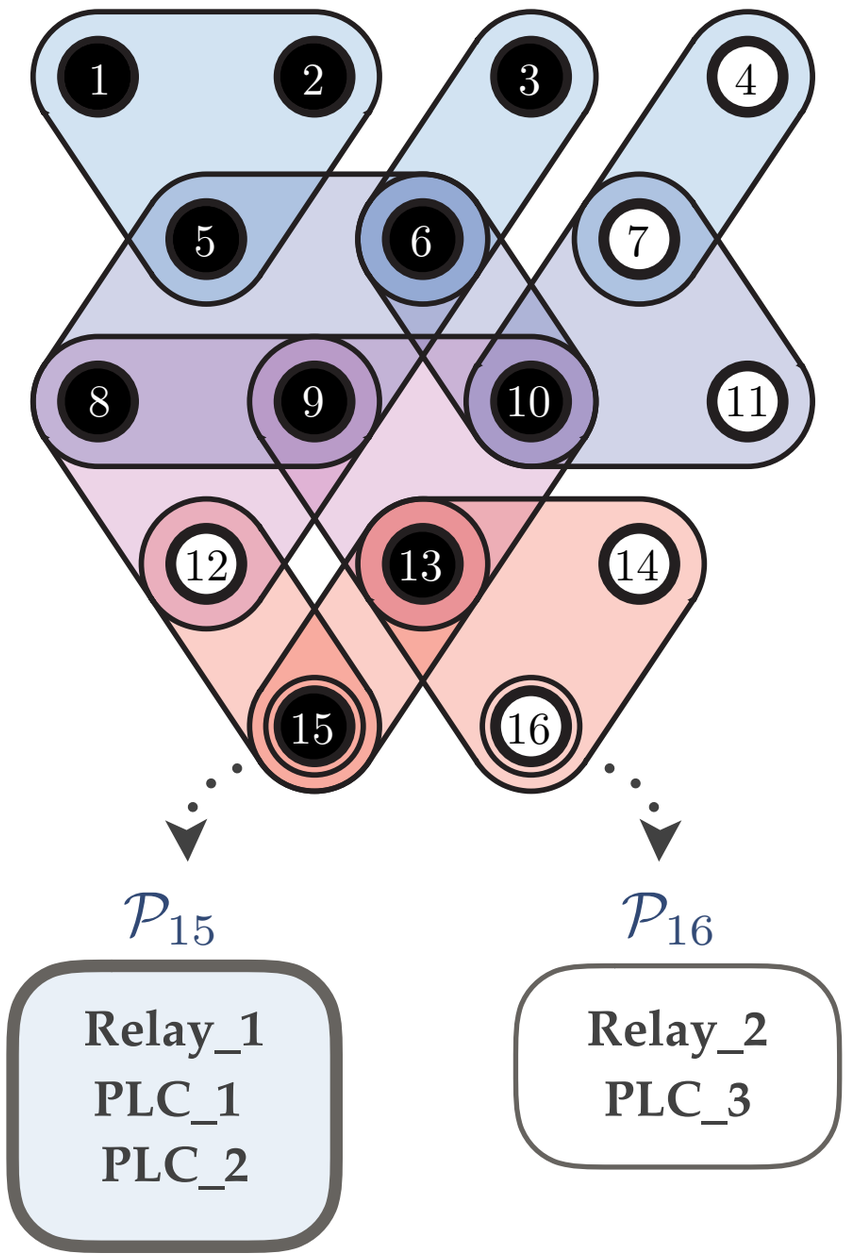
- Attacker can then trigger **physical failures**
  - Severity is dependent upon the current **physical state, x_t**



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Operating Modes

- The defender wishes to continue to operate the system, at reduced performance, while it is under attack
- Define set of **operating modes,** $\mathcal{M}$,
- Each operating mode $m \in \mathcal{M}$ defines a structure for:

cyber network

- port connectivity, active services, trust relationships

$\xRightarrow[\text{analysis}]{\text{vulnerability}}$ dependency graph

physical network

- status of relays, breakers, sensors, valves

$\Rightarrow$ physical network topology

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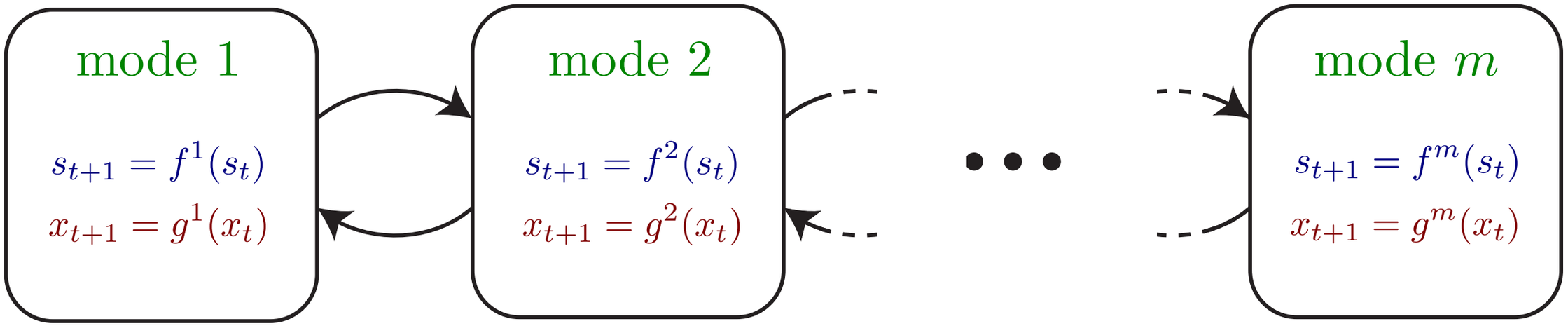
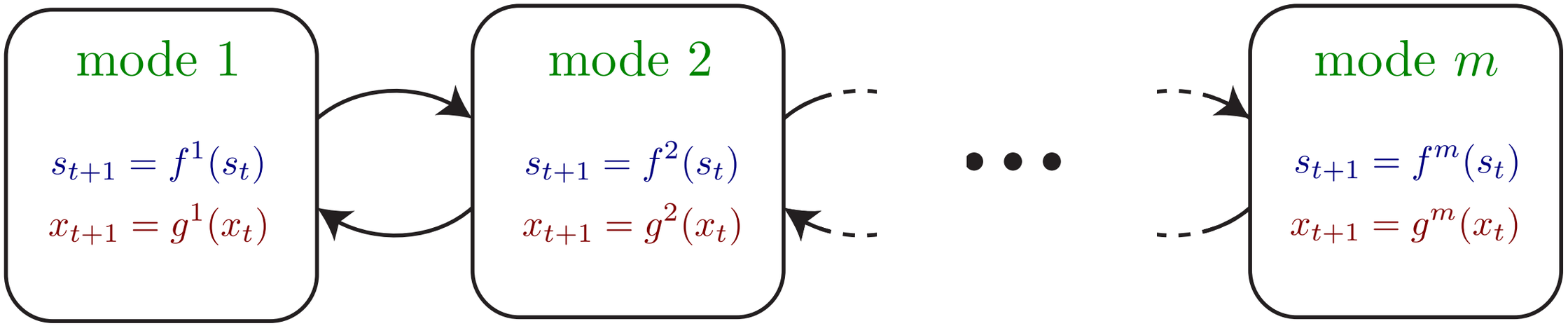
Operating Modes



Operating Modes



- **Defense Problem:** The defender uses its belief of (s_t, x_t) to **control** the transitions between **operating modes**
  - The defender is attempting to maximally interfere with the progression of the attacker while maintaining functionality of the network

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Ongoing Work

- Past work on the **defense of cyber networks**
  - *E. Miehling, M. Rasouli, and D. Teneketzis.* **Optimal Defense Policies for Partially Observable Spreading Processes on Bayesian Attack Graphs** (MTD Workshop — CCS 2015)
  - *E. Miehling, M. Rasouli, and D. Teneketzis.* **A POMDP Approach to Autonomic, Dynamic Defense of Large-Scale Cyber Networks** (to be submitted to IEEE Transactions on Information Forensics and Security)
- Current work is focused on **integrating the physical system**

Summary

- The model allows us to relate attacker capabilities to spatial regions of the physical infrastructure
- The **security state** tells us likely physical contingencies and, coupled with the **physical state**, the severity of the potential damage
- Controlling the **operating mode** decreases the chances that the attack will succeed ***and*** ensures that the system is prepared for any contingencies

Acknowledgments

- Special thanks to the following funding sources

- **NSF —** Foundations Of Resilient CybEr-physical Systems (FORCES)

  Grant: CNS-1238962

- **ARO MURI —** Adversarial and Uncertain Reasoning for Adaptive Cyber Defense: Building the Scientific Foundations

  Grant: W911NF-13-1-0421

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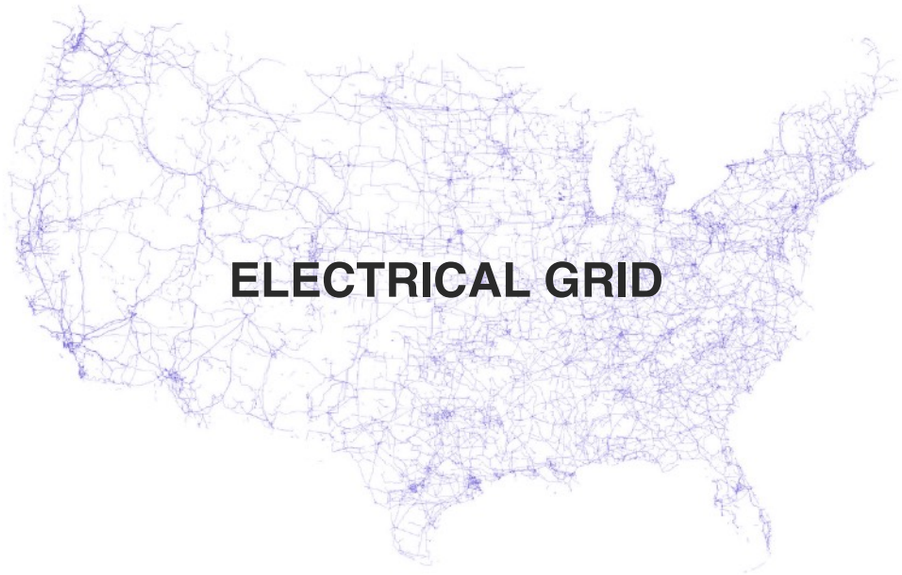

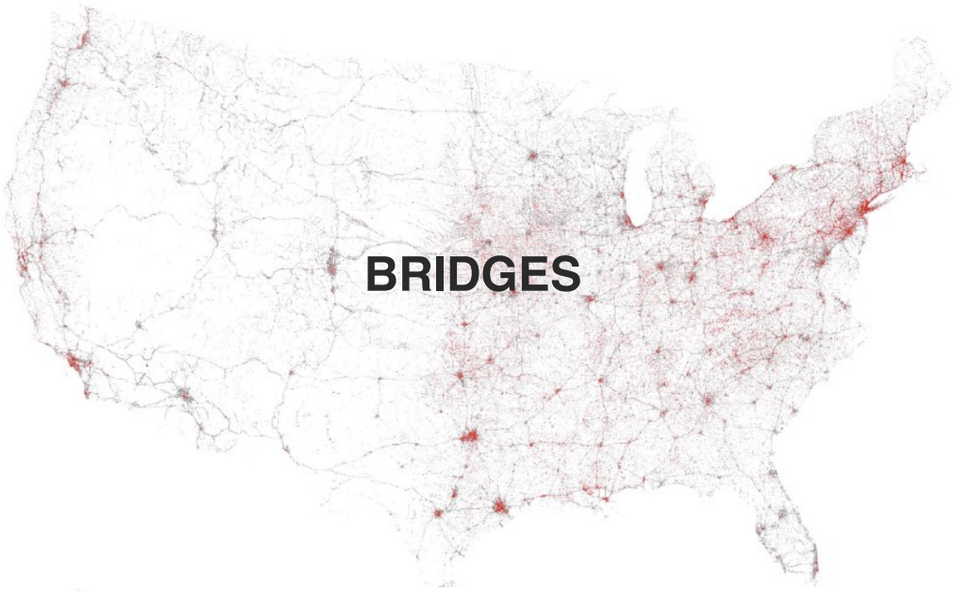

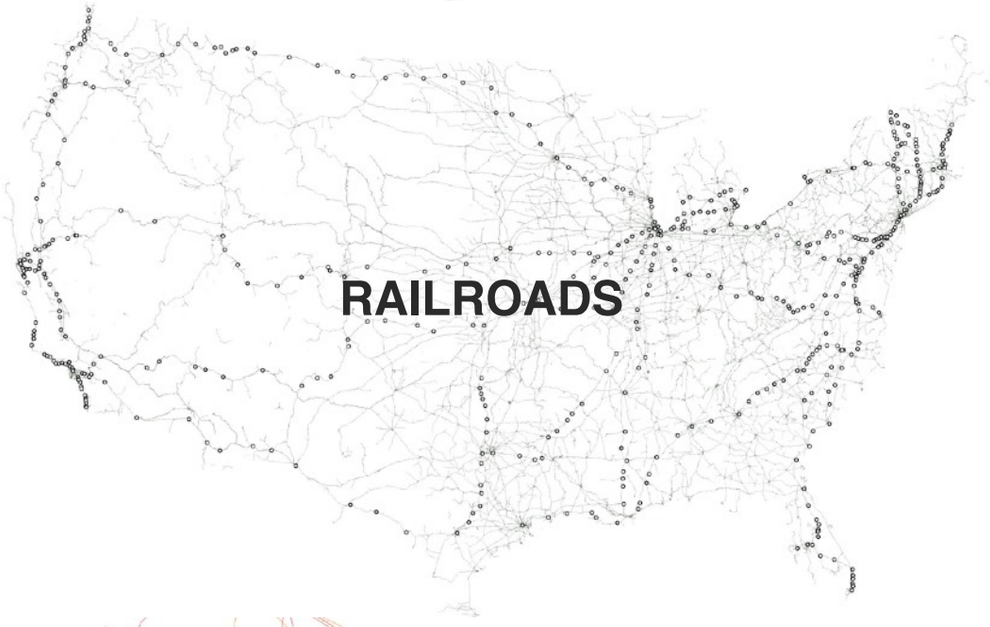

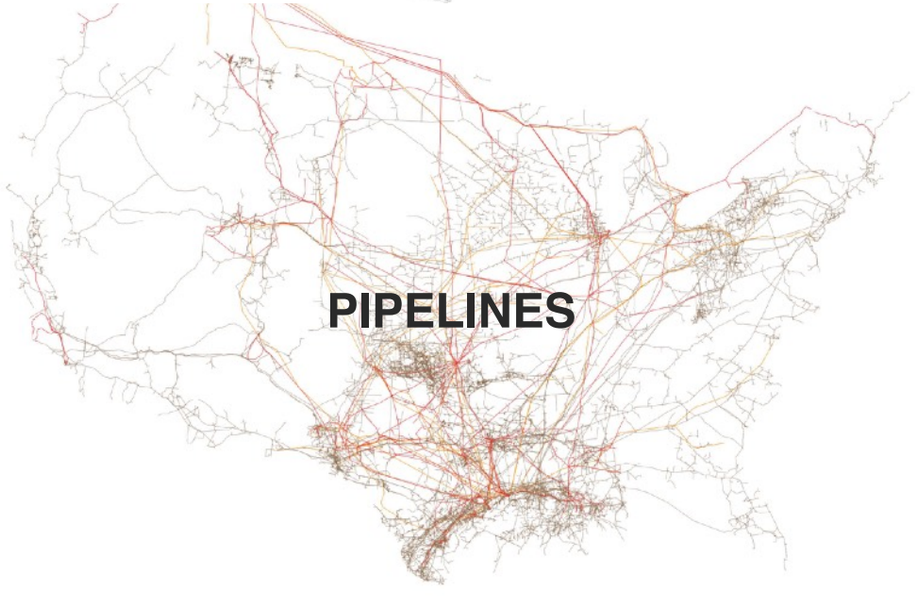

Tim Meko, “Six maps that show the anatomy of America’s vast infrastructure,” The Washington Post, 2017