Foundational and Systems Support for Quantitative Trust Management (QTM)

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Computer and Information Science

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ONR MURI N00014-07-1-0907

Review Meeting

November 4, 2009

Project Team

Principal Investigators

- **Sampath Kannan** (Ph.D 89, Berkeley)
  Stream Algorithms, Run-time monitoring, Cryptography
- **Insup Lee** (Ph.D. 83, Wisconsin)
  Real-time and cyber-physical systems, Run-time monitoring
- **Matt Blaze** (Ph.D. 93, Princeton)
  Network security, Cryptography, Trust Management
- **Oleg Sokolsky** (Ph.D. 96, SUNY-SB)
  Formal methods, Real-time and hybrid systems
- **Jonathan Smith** (Ph.D. 89, Columbia)
  Networking, Security and privacy, Mobility
- **Angelos Keromytis** (Ph.D. 01, Penn)
  Computer security, Cryptography, Networking
- **Wenke Lee** (Ph.D. 99, Columbia)
  System and network security, Applied cryptography, Data mining

- Students
  - Adam Aviv, Jian Chang, Nikhil Dinesh, Zhiyi Huang, Andrew West, David Dagon, Manos Antonakakis, Matt Burnside, Vasilis Pappas, Stelios Sidiroglou
- Postdocs
  - Daniel Luo, Vinayak Prabhu, Krishna Venkatasubramanian,
- Collaborators
  - Nick Feamster, Boon Loo, Aravind Joshi, Jason Nieh

Trust

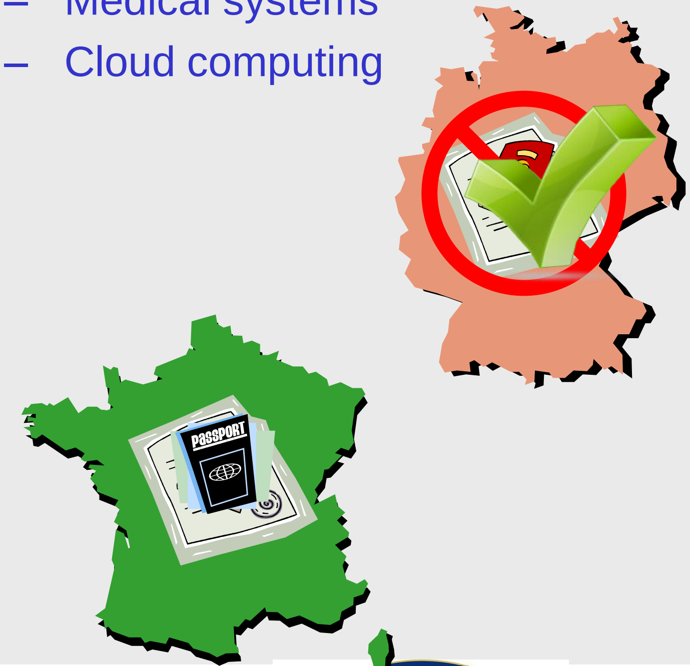
- Webster's Dictionary: TRUST, -noun:
  - (1) Assured reliance on the character, ability, strength, or truth of someone or something.
  - (2) One in which confidence is placed.

- Our Definition:
  - Trust is the expectation of a **trustor** with respect to certain properties of a **trustee** or her actions under a specified **context** and **time**, considering the **risks**, **incentives**, and **historical information**.

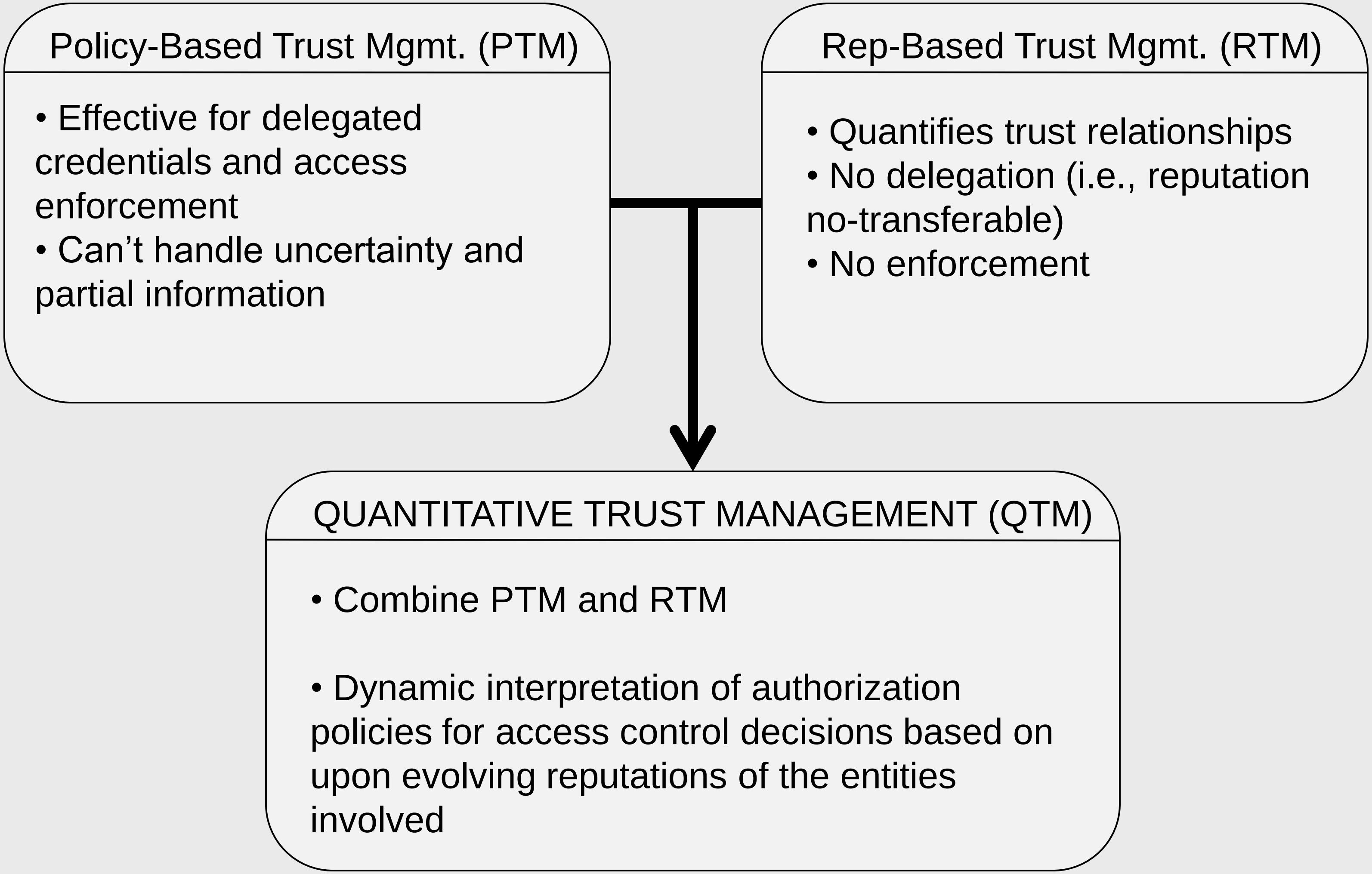
The Problem of Trust

- *Quantitative Trust* for federated networked systems
  - Decentralized policies
  - Dynamic environment, partial trust
  - Complex “trust” models (logic + reputation), in reality

- Applications
  - E-commerce systems
  - Service compositions in GIG
  - Reusing components/subsystem in complex DoD systems
  - Social Networks
  - Medical systems
  - Cloud computing



Trust Management



Policy-Based Trust Mgmt. (PTM)

- Effective for delegated credentials and access enforcement
- Can’t handle uncertainty and partial information

Rep-Based Trust Mgmt. (RTM)

- Quantifies trust relationships
- No delegation (i.e., reputation no-transferable)
- No enforcement

QUANTITATIVE TRUST MANAGEMENT (QTM)

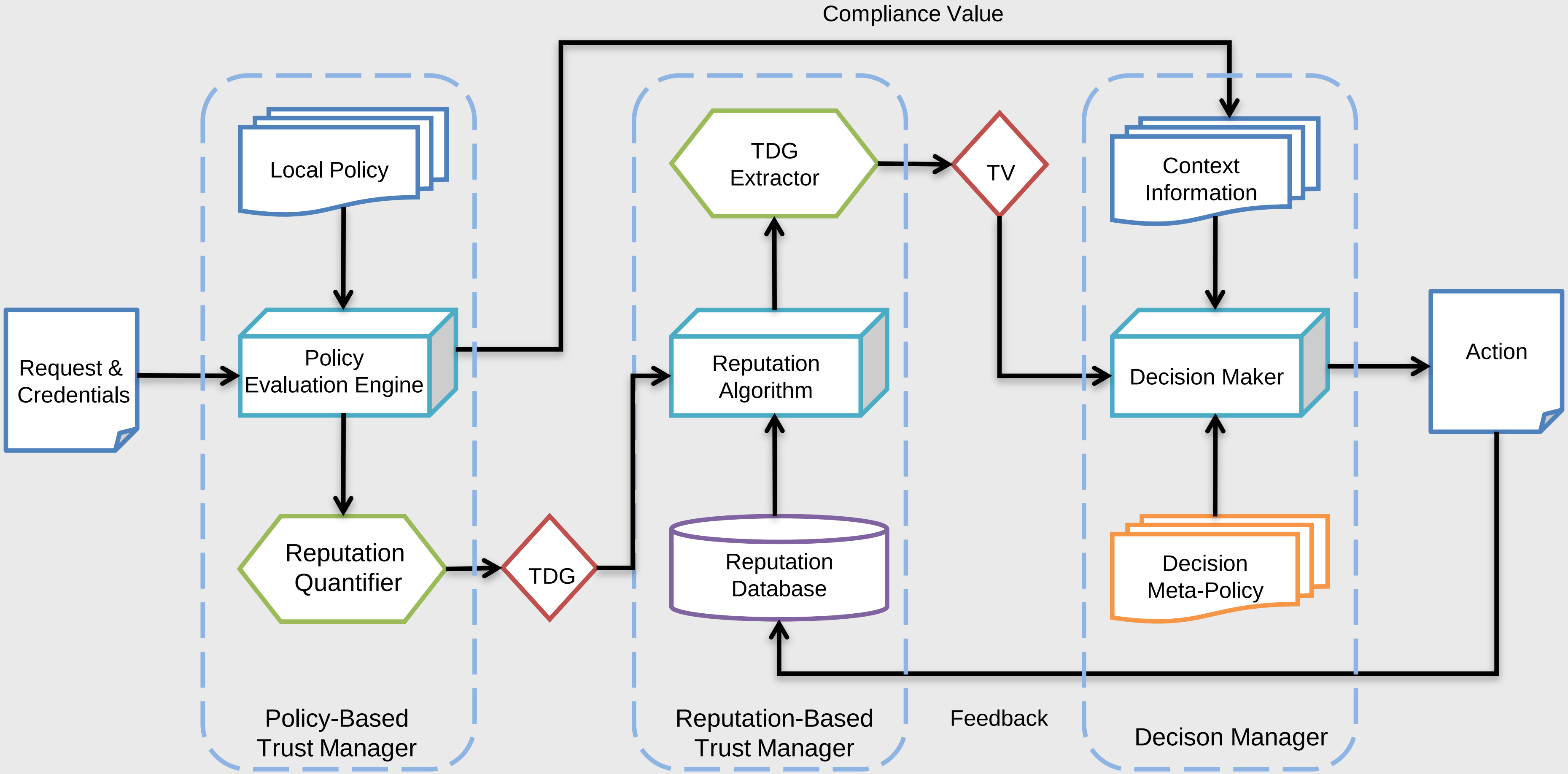
- Combine PTM and RTM

- Dynamic interpretation of authorization policies for access control decisions based on upon evolving reputations of the entities involved

QTM Challenges

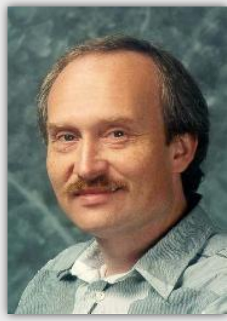
- What are some metrics for effectiveness of TM systems?
- How do we incorporate uncertainty in policy-based TM's?
- How do we incorporate dynamism in policy-based TM's?
- How can we model adversaries as **economic agents** and develop a **game-theoretic view** of trust management?
- Can we build new reputation management systems based on sound principles?
- What is the proper way to mathematically **combine reputations**?
  - Involves integration of logical/quantitative/probabilistic reasoning
  - Is there a means to build consensus from distributed observations?
- How do we **integrate** policy-based and reputation-based TMs?
- What are some important applications of TM systems?

Quantitative Trust Management (QTM)



Collaboration

Policy-based Trust Management (PTM)



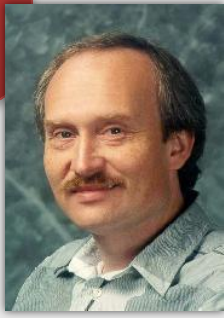
KeyNote PTM Systems

Permission-to-Speak

Dynamic Trust Management Arachne

Collaboration

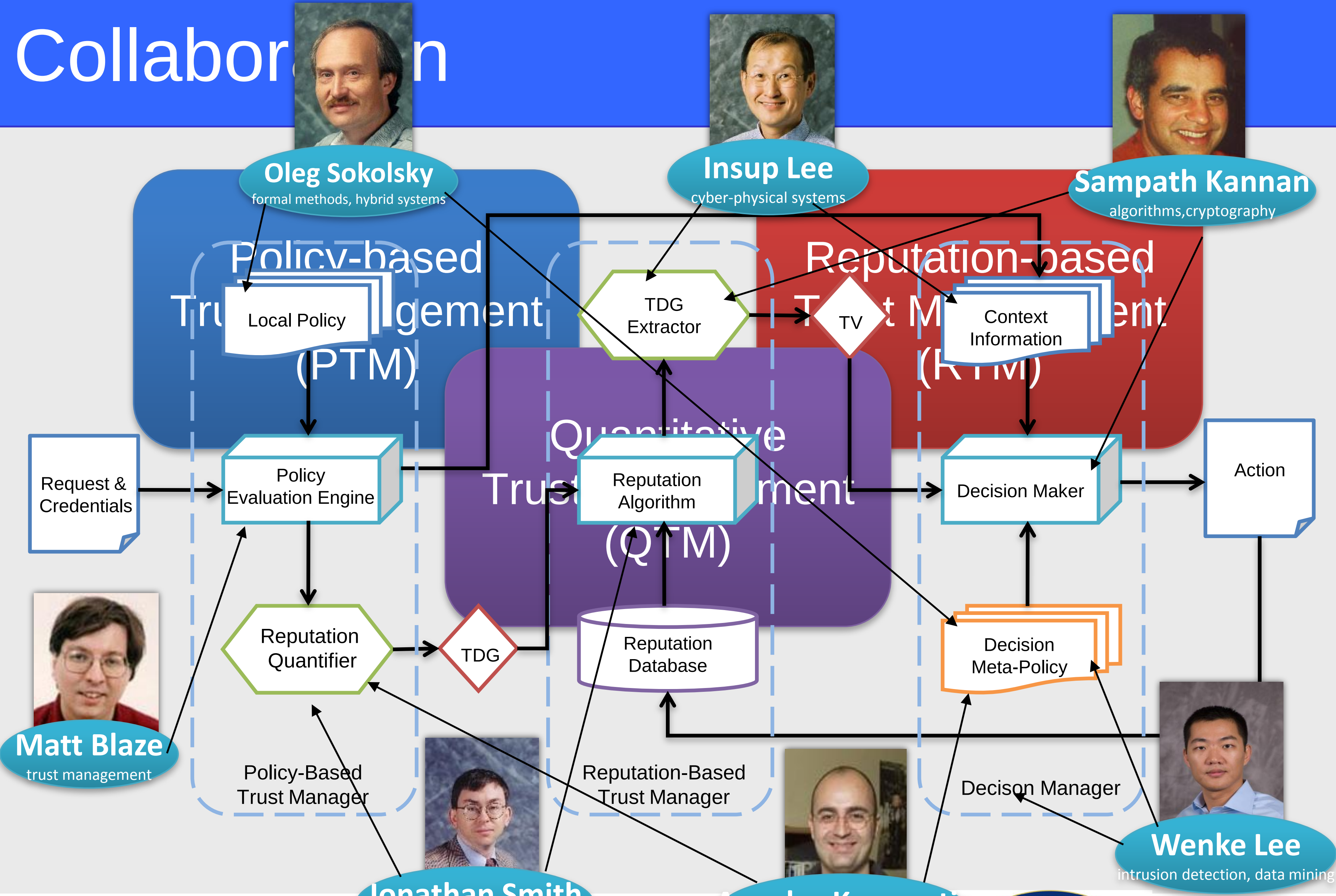
Reputation-based Trust Management (RTM)



Evaluating RTM Systems

Blacklist as Feedback of Reputation Management

Collabor n



Oleg Sokolsky
formal methods, hybrid systems

Insup Lee
cyber-physical systems

Sampath Kannan
algorithms,cryptography

Policy-based Trust Management (PTM)

Reputation-based Trust Management (RTM)

Quantitative Trust Management (QTM)

Local Policy

TDG Extractor

TV

Context Information

Request & Credentials

Policy Evaluation Engine

Reputation Algorithm

Decision Maker

Action

Reputation Quantifier

TDG

Reputation Database

Decision Meta-Policy

Policy-Based Trust Manager

Reputation-Based Trust Manager

Decison Manager

Matt Blaze
trust management

Jonathan Smith
network security and privacy

Angelos Keromytis
network security, cryptography

Wenke Lee
intrusion detection, data mining

Team Efforts

- Several Research Collaborations
  - Distributed TM, Dynamic TM, Spatio-Temporal Reputations, …
  - Keynote-base QTM
- Annual meetings
  - 2007, 2008, 2009
- Many Tele-conferences and Student Visits
  - Penn -> GA Tech, Columbia -> Penn, GA Tech -> Penn
- Collaborative case studies
  - SPAM list and BGP security as QTM application
- PhD Dissertation Committees
  - Matt Burnside (Columbia)
  - David Dagon (GA Tech)
  - Andrew West (Penn)

Education

- Courses
  - Integrated material into COMS W4180 course (Columbia)
  - CIS 125 new course on understanding of existing and emerging technologies, along with the political, societal and economic impacts of those technologies (Penn)
  - Integrated material into CIS 551 (Penn)
  - Material on botnet detection added to Network Security classes: undergraduate cs4237, and graduate cs6262 (GA Tech)
  - 3 senior design projects (Penn)
- Workforce training
  - 3 post-docs
  - 10 Ph.D. students
  - 1 Masters and 1 undergraduate

Publication

- Publications
  - 7 journal articles
  - 2 book chapter
  - 33 conference papers
- Selected papers
  - M. Blaze, S. Kannan, I. Lee, O. Sokolsky, J.M. Smith, A.D. Keromytis, and W. Lee. Dynamic Trust Management, In IEEE Computer Magazine, vol. 42, no. 2, pp. 44 - 52, February 2009.
  - A.G. West, A.J. Aviv, J. Chang, V. Prabhu, M. Blaze, S. Kannan, I. Lee, J.M. Smith, and O. Sokolsky. QuanTM: A Quantitative Trust Management System. EUROSEC 2009, pp. 28-35.
  - A.G. West, I. Lee, S. Kannan, and O. Sokolsky. An Evaluation Framework for Reputation Management Systems. In *Trust Modeling and Management in Digital Environments: From Social Concept to System Development* (Zheng Yan, ed.), 2009.

Dissemination & Tech transfer

- Beyond conference talks
  - 7 invited and 2 keynote talks, 6 panels
- Working with Symantec to determine modus operandi of rogue Antivirus sites (and why users trust them)
  - Interim Symantec Threat Report (ISTR), Oct 09
- Working with Damballa to deliver botnet detection and mitigation technologies to government and enterprise customers
  - Botnet detection system such BotMiner malware analysis technologies, and the DNS-based monitoring technologies
  - Several Ph.D. students did summer internship
  - Several Damballa researchers were former students at Georgia Tech, and still participate in some of the research meetings at Georgia Tech
- Matt Burnside now working for NSA
- QTM ideas used in ONR-supported "Networks Opposing Botnets" (NoBot) project, withPenn, Harvard and Princeton

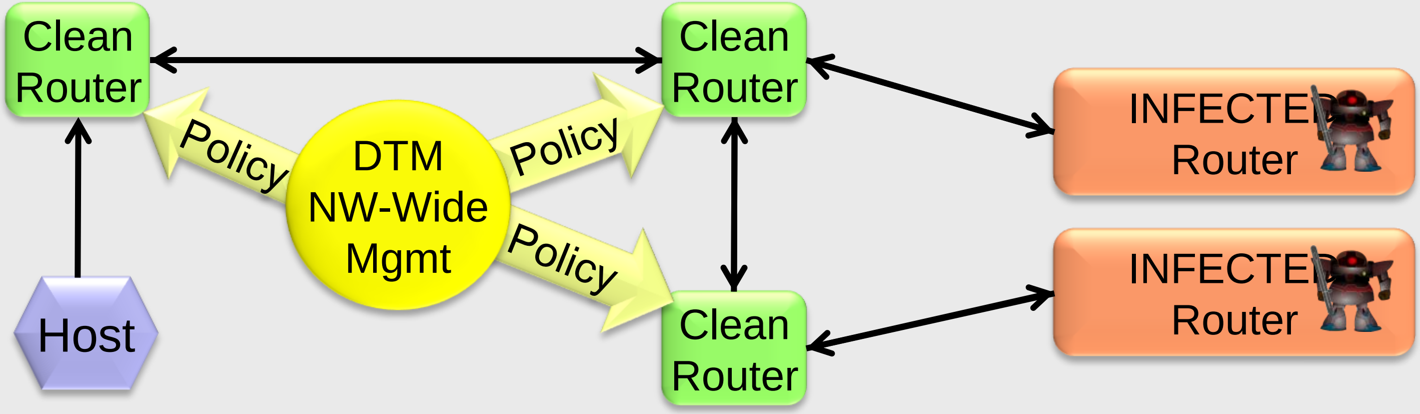
Research highlights

- Project Overview, Insup Lee (PI)
- Trust Management, Matt Blaze
- Dynamic Trust Management, Jonathan M. Smith
- Exposing Trust Assumptions in Distributed Policy Enforcement, Angelos Keromytis
- Permission to Speak: A Novel Formal Foundation for Access Control, Oleg Sokolsky
- Dynamic IP Reputation from DNS, Wenke Lee
- Using Spatiotemporal Reputation to Predict Malicious Behaviors, Andrew West
- Reputations and Games, Sampath Kannan
- Future Work and Discussion, Insup Lee

Dynamic Trust Management

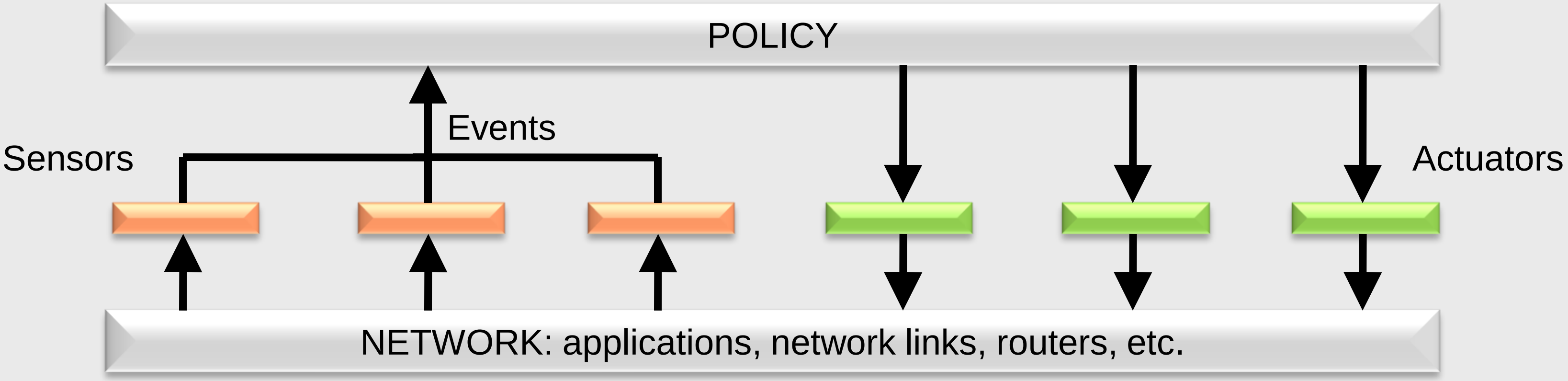
(Penn + Columbia + Georgia Tech)

- A COOPERATIVE and DYNAMIC policy evaluation infrastructure that will enable such critical capabilities as:
  - Adaptation to dynamic service availability
  - Complex situational dynamics (e.g., differentiating between bot-net and physical attacks on infrastructure).
- BENEFITS of a Dynamic Trust Management approach
  - Flexible and robust control of authorizations in complex distributed systems such as the DoD/IC GIG
  - The ability to define policies for scalable decentralized defense against emergent cyber-threats by rapid adaptation of resource access limits.



Arachne: Coordinated Policy Enforcement

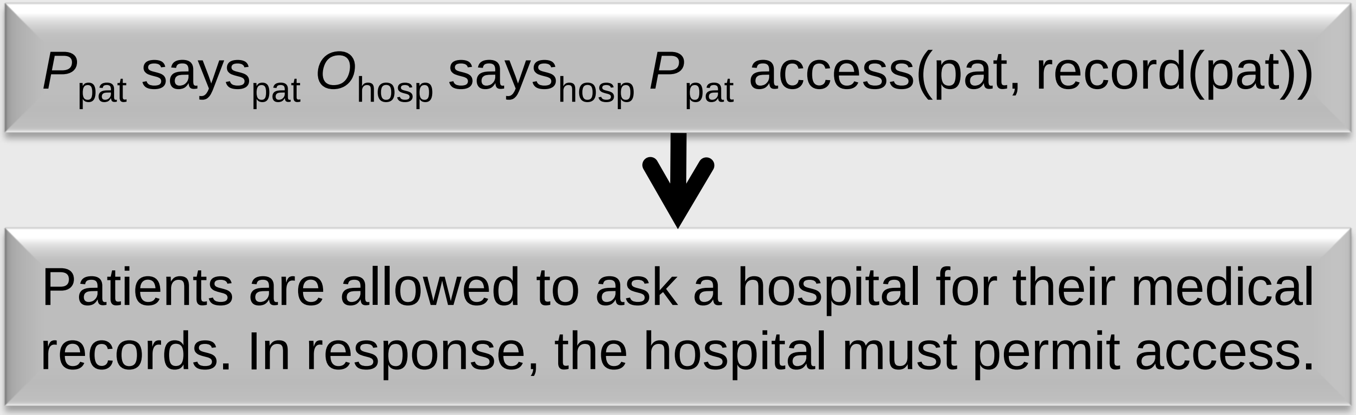
(Columbia)



- ARACHNE is a system for the coordinated distribution and evaluation of a system-wide policy on different nodes
  - Several prototype systems for enterprise-level security have been developed
- GOAL: Integrate a variety of different, diverse security mechanisms and policy expression methods
  - Achieve enhanced protection over any individual method
  - Allow exchange of information between different mechanisms (Eliminate the possibility of “locally correct” but globally wrong decisions
  - Capture trade-offs between amount of global context, scalability, etc.

Permission-to-Speak

- A new policy deontic logic developed under ONR-MURI
- Explicit representation of PERMISSIONS and OBLIGATIONS imposed by a policy, and the delegation of policies.
  - Captures notions such as ‘allow to require’ which are necessary for dynamic policy introduction.
- Explicit representation of policy DEPENDENCIES
  - Iterative algorithm for calculating the set of relevant policy statements
- Logic prog.-based evaluation allows efficient blame assignment

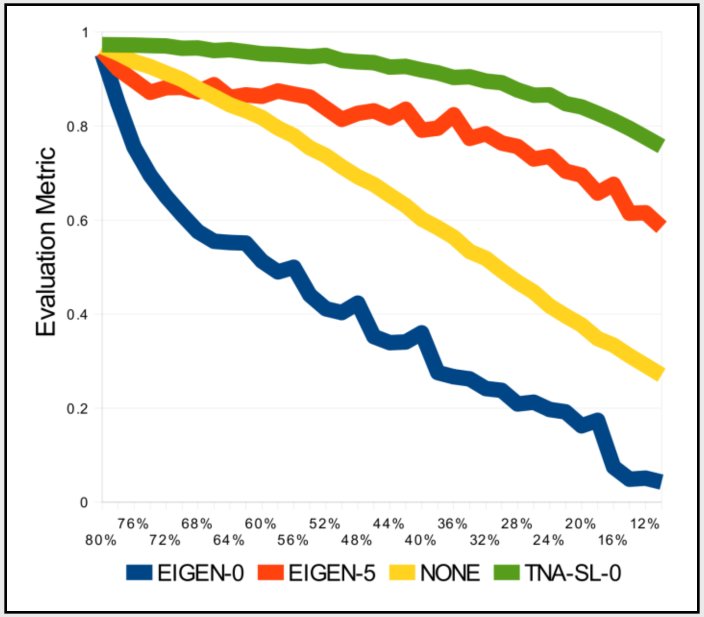


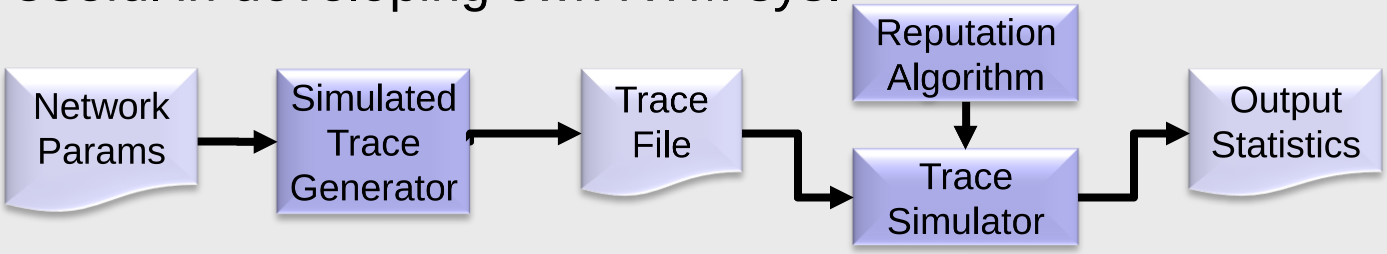
$P_{\mathrm{pat}}\ \mathrm{says}_{\mathrm{pat}}\ O_{\mathrm{hosp}}\ \mathrm{says}_{\mathrm{hosp}}\ P_{\mathrm{pat}}\ \mathrm{access}(\mathrm{pat}, \mathrm{record}(\mathrm{pat}))$

Patients are allowed to ask a hospital for their medical records. In response, the hospital must permit access.

Evaluating RTM Systems

- Many reputation systems are available in the literature
  - EigenTrust, TNA-SL (Trusted Network Analysis with Subjective Logic), …
  - Little or no comparison between them
- Designed and implemented a framework for comparative evaluation of reputation systems
  - Identified evaluation criteria
  - Generation of evaluation scenarios
  - Development of malicious strategies
  - Collection of statistics and analysis
- Useful in developing own RTM sys.





Network Params → Simulated Trace Generator → Trace File → Trace Simulator

Reputation Algorithm → Trace Simulator → Output Statistics

Dynamic IP Reputation from DNS

(Georgia Tech)

- Dynamic Domain Name reputation using passive DNS (pDNS)
  - Professional DNS hosting differs from non-professional
  - pDNS information is already present in our network
  - Static IP/DNS blacklists have limitations
  - Malicious Users tend to reuse their infrastructure
- Contributions:
  - Zone and network based clustering of pDNS
  - A new method of assigning reputation on new RRSETs using limited {White/Grey/Black}-listing
  - A dynamic Domain Name reputation rating system
    - Always maintain fresh reputation knowledge based on pDNS

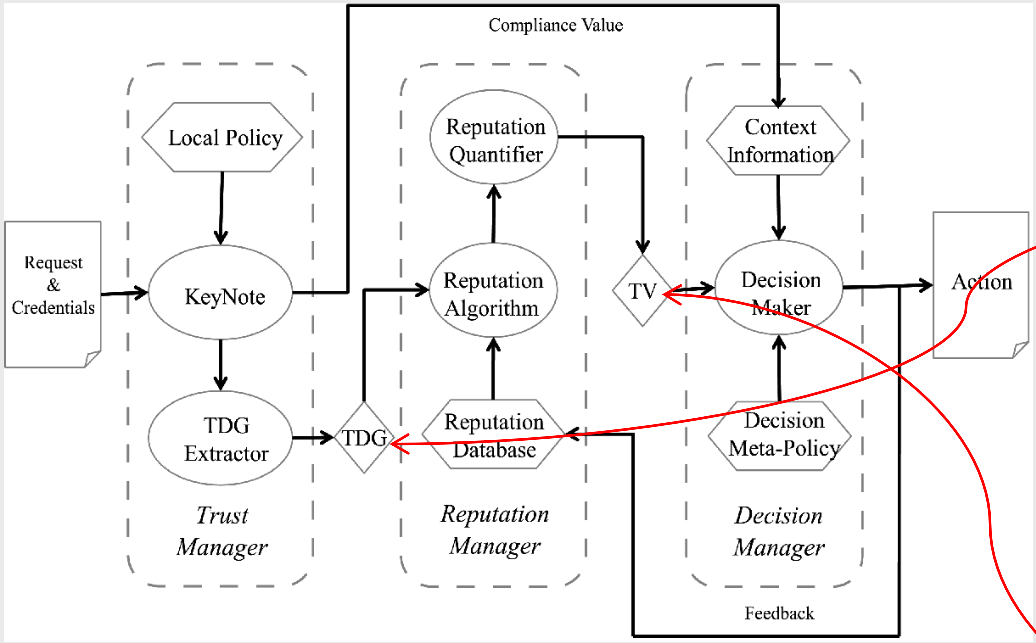
Spatio-Temporal Reputation

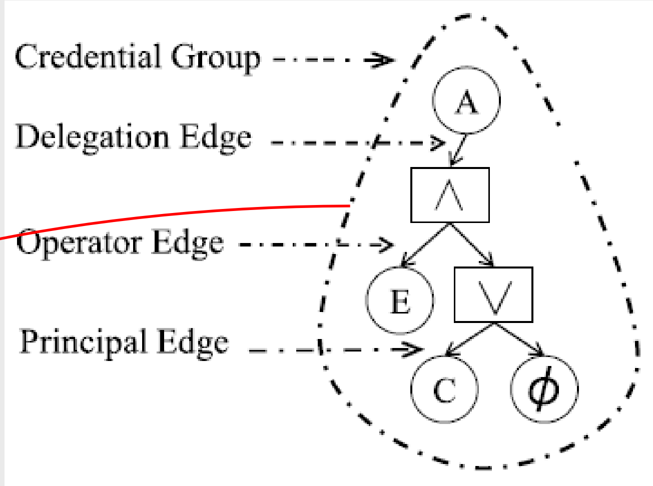
(Penn + Georgia Tech)

- As the RM part of QTM, we have developed reputation-bases trust management based on spatiotemporal reputation
- Approach
  - Assumptions
    - Bad guys are geographically clustered (spatio)
    - Bad guys are likely to repeat bad behaviors (temporal)
  - Given
    - A historical record of those principals known to be bad, and the time when this was noted (feedback)
  - Produce
    - An extended list of principals who are thought to be bad at the current time, based on their own past history, and the history of those around them
- Case studies: Spam filter based on IP blacklist, wikipedia

Quantitative Trust Management (QTM)

- QTM provides a dynamic interpretation of authorization policies for access control decisions using evolving reputations of parties
- *QuanTM* is a QTM system that combines elements from PTM and RTM to create a novel method for trust evaluation





Trust Dependency Graph (TDG), encoding PTM relationships useful for RTM

Reputations of PRINCIPALS, DELEGATIONS and CREDENTIALS are aggregated

The QuanTM Architecture