Theorem Proving for Certified Mission Assurance

Shiu-Kai Chin
Professor, Dept. of Electrical Engineering & Computer Science
Syracuse University, Syracuse, New York
Senior Scientist, Serco-NA, Rome, New York

Acknowledgements

This is joint work with:

- Susan Older, Ph.D., Syracuse University
- Sarah Muccio, Ph.D., Air Force Research Laboratory
- Thomas (TJ) Vestal, Air Force Research Laboratory
- Fred Wieners, Col. USAF (ret), Serco-NA
- Lockwood Morris, Ph.D., Syracuse University

Why Mission Assurance Matters

Major General Richard Webber, Commander, 24^{th} Air Force

- "Mission assurance is the number one goal in current cyber operations, versus the old paradigm of information assurance."

Definitions

- **Mission Assurance:** assuring that critical system capabilities necessary to complete a mission successfully are available, correctly implemented, and secure
- **Information Assurance:** measures that protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation

Eugene Spafford

- "There are limits to how much you can fireproof a cardboard box."

Why *Certified & Verified* Mission Assurance Matters

Dr. Kamal Jabbour, ST, Senior Scientist for Information Assurance, USAF

- "Modifying the cyberspace domain to eliminate vulnerabilities or make them inaccessible to an adversary through sound hardware and software development practices can eliminate beforehand vulnerabilities by designing them out of a system."
- "I want theorems!"

Need: A science & engineering for mission assurance

Purpose & Preview

Purpose

- Describe some of our efforts to develop and apply mathematical logic for mission assurance
- Show that the logic, proofs, and methods are well within the capabilities of practicing engineers

Preview

- Introduction: intended audience, focus, & viewpoint
- Overview of the logic
- Representation of CONOPS & an example
- Conclusions

Introduction

Intended audience

- Designers, builders, specifiers, buyers, and evaluators of secure and trustworthy computer and information systems

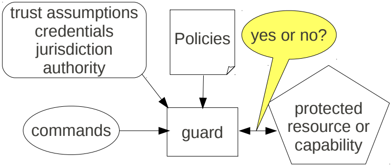
Focus: access policies and concepts of operation

- Hardware, virtual machines, networks
- Credentials, authority, delegation
- Confidentiality & integrity policies

Logic is a means to an end

- Means of description
- Inference rules
- Theorem-based design & verification (proofs)

Our Viewpoint



When given a command/request, trust assumptions, credentials, jurisdiction, authority, and policy

- Logically justify if the command/request is honored or not
- Anything less is regarded as a don't know, don't care, or incompetence

No different for hardware designers and verifiers

A Logical Approach to Access Control

Access-control logic as a tool

- Modification of multi-agent propositional modal logic created by Abadi, Burrows, Lampson, and Plotkin
- Implemented as a conservative extension to the Cambridge Higher Order Logic (HOL-4) Kananaskis 7 theorem prover (joint work with Lockwood Morris)
- Routinely taught to SU graduate students in *Principles of Distributed Access Control* course
- Used since 2003 by over 226 ROTC cadets from over 40 universities as part of Air Force Research Lab's *Advanced Course in Engineering for Cybersecurity Bootcamp*

Methods usable by practicing engineers and provide assurance

Our focus: Concept of Operations (CONOPS)

CONOPS definition

"The CONOPS clearly and concisely expresses what [is to be] accomplish[ed] and how it will be done using available resources. It describes how the actions of . . . components and supporting organizations will be integrated, synchronized, and phased to accomplish the mission . . ."

JP 5-0, Joint Operation Planning

Why focus on CONOPS?

- Reveals the thinking of commanders in terms of mission requirements, critical capabilities, policies, jurisdiction, and trust assumptions
- Mission assurance requires commanders and implementers precisely and accurately agree on the CONOPS

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_\mathcal{M}[\![p]\!] & = & I(p) \\
\mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] & = & W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] & = & \{w \mid J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\
\mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \mid Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
& & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \mid J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$P ::= A \;/\; P \,\&\, Q \;/\; P \,|\, Q$$

$$\varphi ::= p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/\; P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi$$

Kripke structures

$$\begin{aligned} W &= \text{non-empty } \{\text{worlds}\} \\ I &= \mathbf{PropVar} \to \mathcal{P}(W) \\ J &= \mathbf{PName} \to \mathcal{P}(W \times W) \\ \mathcal{M} &= \langle W, I, J \rangle \end{aligned}$$

Semantics

$$\begin{aligned} \mathcal{E}_{\mathcal{M}}[\![p]\!] &= I(p) \\ \mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] &= W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\ \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\ \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\ \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] &= (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\ \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\ \mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] &= \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\ \mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] &= \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\ \mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] &= \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\ \mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] &= \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!] \end{aligned}$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \mid Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_\mathcal{M}[\![p]\!] & = & I(p) \\
\mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] & = & W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] & = & \{w \mid J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\
\mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$P ::= A \;/\; P \,\&\, Q \;/\; P \mid Q$$

$$\varphi ::= p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/\; P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi$$

Kripke structures

$$\begin{aligned} W &= \text{non-empty } \{\text{worlds}\} \\ I &= \textbf{PropVar} \to \mathcal{P}(W) \\ J &= \textbf{PName} \to \mathcal{P}(W \times W) \\ \mathcal{M} &= \langle W, I, J \rangle \end{aligned}$$

Semantics

$$\begin{aligned}
\mathcal{E}_{\mathcal{M}}[\![p]\!] &= I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] &= W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] &= (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] &= \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] &= \{w \mid J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] &= \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] &= \mathcal{E}_{\mathcal{M}}[\![P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{aligned}$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{aligned}
P &::= A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi &::= p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
&\qquad P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{aligned}
$$

Kripke structures

$$
\begin{aligned}
W &= \text{non-empty } \{\text{worlds}\} \\
I &= \textbf{PropVar} \to \mathcal{P}(W) \\
J &= \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} &= \langle W, I, J \rangle
\end{aligned}
$$

Semantics

$$
\begin{aligned}
\mathcal{E}_{\mathcal{M}}[\![p]\!] &= I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] &= W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] &= (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] &= \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] &= \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] &= \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] &= \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] &= \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{aligned}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \rightarrow \mathcal{P}(W) \\
J & = & \textbf{PName} \rightarrow \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_\mathcal{M}[\![p]\!] & = & I(p) \\
\mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] & = & W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\
\mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$\begin{array}{lcl} P & ::= & A \ / \ P \,\&\, Q \ / \ P \,|\, Q \\ \varphi & ::= & p \ / \ \neg\varphi \ / \ \varphi_1 \wedge \varphi_2 \ / \ \varphi_1 \vee \varphi_2 \ / \ \varphi_1 \supset \varphi_2 \ / \ \varphi_1 \equiv \varphi_2 \ / \\ & & P \Rightarrow Q \ / \ P \text{ says } \varphi \ / \ P \text{ controls } \varphi \ / \ P \text{ reps } Q \text{ on } \varphi \end{array}$$

Kripke structures

$$\begin{array}{lcl} W & = & \text{non-empty } \{\text{worlds}\} \\ I & = & \textbf{PropVar} \to \mathcal{P}(W) \\ J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\ \mathcal{M} & = & \langle W, I, J \rangle \end{array}$$

Semantics

$$\begin{array}{rcl} \mathcal{E}_\mathcal{M}[\![p]\!] & = & I(p) \\ \mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] & = & W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\ \mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\ \mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\ \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\ \mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\ \mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\ \mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] & = & \{w | J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\ \mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\ \mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!] \end{array}$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_\mathcal{M}[\![p]\!] & = & I(p) \\
\mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] & = & W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\
\mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lll}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lll}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \mid Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \mid J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{aligned}
P &::= A \;/\; P \,\&\, Q \;/\; P \,|\, Q \\
\varphi &::= p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
&\quad\; P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{aligned}
$$

Kripke structures

$$
\begin{aligned}
W &= \text{non-empty } \{\text{worlds}\} \\
I &= \textbf{PropVar} \to \mathcal{P}(W) \\
J &= \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} &= \langle W, I, J \rangle
\end{aligned}
$$

Semantics

$$
\begin{aligned}
\mathcal{E}_\mathcal{M}[\![p]\!] &= I(p) \\
\mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] &= W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] &= \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] &= \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] &= (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] &= \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] &= \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] &= \{w \mid J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\
\mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] &= \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] &= \mathcal{E}_\mathcal{M}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{aligned}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P\,\&\,Q \;/\; P \,|\, Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \,|\, J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \,|\, Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lcl}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \mid Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lcl}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \rightarrow \mathcal{P}(W) \\
J & = & \textbf{PName} \rightarrow \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_{\mathcal{M}}[\![p]\!] & = & I(p) \\
\mathcal{E}_{\mathcal{M}}[\![\neg\varphi]\!] & = & W - \mathcal{E}_{\mathcal{M}}[\![\varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!] \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_{\mathcal{M}}[\![\varphi_1]\!]) \cup \mathcal{E}_{\mathcal{M}}[\![\varphi_2]\!] \\
\mathcal{E}_{\mathcal{M}}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_{\mathcal{M}}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_{\mathcal{M}}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ says } \varphi]\!] & = & \{w \mid J(P)(w) \subseteq \mathcal{E}_{\mathcal{M}}[\![\varphi]\!]\} \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_{\mathcal{M}}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_{\mathcal{M}}[\![P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

$$
\begin{array}{lll}
P & ::= & A \;/\; P \,\&\, Q \;/\; P \mid Q \\
\varphi & ::= & p \;/\; \neg\varphi \;/\; \varphi_1 \wedge \varphi_2 \;/\; \varphi_1 \vee \varphi_2 \;/\; \varphi_1 \supset \varphi_2 \;/\; \varphi_1 \equiv \varphi_2 \;/ \\
 & & P \Rightarrow Q \;/\; P \text{ says } \varphi \;/\; P \text{ controls } \varphi \;/\; P \text{ reps } Q \text{ on } \varphi
\end{array}
$$

Kripke structures

$$
\begin{array}{lll}
W & = & \text{non-empty } \{\text{worlds}\} \\
I & = & \textbf{PropVar} \to \mathcal{P}(W) \\
J & = & \textbf{PName} \to \mathcal{P}(W \times W) \\
\mathcal{M} & = & \langle W, I, J \rangle
\end{array}
$$

Semantics

$$
\begin{array}{rcl}
\mathcal{E}_\mathcal{M}[\![p]\!] & = & I(p) \\
\mathcal{E}_\mathcal{M}[\![\neg\varphi]\!] & = & W - \mathcal{E}_\mathcal{M}[\![\varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \wedge \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \vee \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1]\!] \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] & = & (W - \mathcal{E}_\mathcal{M}[\![\varphi_1]\!]) \cup \mathcal{E}_\mathcal{M}[\![\varphi_2]\!] \\
\mathcal{E}_\mathcal{M}[\![\varphi_1 \equiv \varphi_2]\!] & = & \mathcal{E}_\mathcal{M}[\![\varphi_1 \supset \varphi_2]\!] \cap \mathcal{E}_\mathcal{M}[\![\varphi_2 \supset \varphi_1]\!] \\
\mathcal{E}_\mathcal{M}[\![P \Rightarrow Q]\!] & = & \begin{cases} W, & \text{if } J(Q) \subseteq J(P) \\ \emptyset, & \text{otherwise} \end{cases} \\
\mathcal{E}_\mathcal{M}[\![P \text{ says } \varphi]\!] & = & \{w \mid J(P)(w) \subseteq \mathcal{E}_\mathcal{M}[\![\varphi]\!]\} \\
\mathcal{E}_\mathcal{M}[\![P \text{ controls } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![(P \text{ says } \varphi) \supset \varphi]\!] \\
\mathcal{E}_\mathcal{M}[\![P \text{ reps } Q \text{ on } \varphi]\!] & = & \mathcal{E}_\mathcal{M}[\![P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi]\!]
\end{array}
$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_{\mathcal{M}}[\![H_i]\!] = W$

then $\mathcal{E}_{\mathcal{M}}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\frac{H_1 \cdots H_n}{C}$ instead

Soundness

$\frac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

$$\text{If all } \mathcal{E}_\mathcal{M}[\![H_i]\!] = W \text{ then } \mathcal{E}_\mathcal{M}[\![C]\!] = W$$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\quad \frac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\quad \frac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ $\qquad$ *Says* $\quad \frac{\varphi}{P \text{ says } \varphi}$

MP Says $\quad \frac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\quad \frac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\quad \frac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\quad \frac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\quad \frac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\quad \frac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\quad \frac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_{\mathcal{M}}[\![H_i]\!] = W$
then $\mathcal{E}_{\mathcal{M}}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\quad \dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\quad \dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ $\qquad$ *Says* $\quad \dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\quad \dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\quad \dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\quad \dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\quad \dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\quad \dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\quad \dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\quad \dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_{\mathcal{M}}[\![H_i]\!] = W$

then $\mathcal{E}_{\mathcal{M}}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures $\mathcal{M}$* and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_{\mathcal{M}}[\![H_i]\!] = W$

then $\mathcal{E}_{\mathcal{M}}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\quad \dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\quad \dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ $\qquad$ *Says* $\quad \dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\quad \dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\quad \dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\quad \dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\quad \dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\quad \dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\quad \dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\quad \dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

$$\text{If all } \mathcal{E}_{\mathcal{M}}[\![H_i]\!] = W$$
$$\text{then } \mathcal{E}_{\mathcal{M}}[\![C]\!] = W$$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\frac{H_1 \cdots H_n}{C}$ instead

Soundness

$\frac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures $\mathcal{M}$* and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_\mathcal{M}[\![H_i]\!] = W$

then $\mathcal{E}_\mathcal{M}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\frac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\frac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\frac{\varphi}{P \text{ says } \varphi}$

MP Says $\frac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\frac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\frac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\frac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\frac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\frac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\frac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$

$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

$$\text{If all } \mathcal{E}_\mathcal{M}[\![H_i]\!] = W$$
$$\text{then } \mathcal{E}_\mathcal{M}[\![C]\!] = W$$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

$$\text{If all } \mathcal{E}_{\mathcal{M}}[\![H_i]\!] = W \text{ then } \mathcal{E}_{\mathcal{M}}[\![C]\!] = W$$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Core inference rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_\mathcal{M}[\![H_i]\!] = W$

then $\mathcal{E}_\mathcal{M}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Inference Rules

Rules

- Inconvenient to use Kripke semantics
- Use inference rules $\dfrac{H_1 \cdots H_n}{C}$ instead

Soundness

$\dfrac{H_1 \cdots H_n}{C}$ is sound if *for all Kripke structures* $\mathcal{M}$ and each $i \in \{1, \ldots, n\}$:

If all $\mathcal{E}_\mathcal{M}[\![H_i]\!] = W$

then $\mathcal{E}_\mathcal{M}[\![C]\!] = W$

- All rules are sound
- All verified in HOL-4 K-7 theorem prover

Core inference rules

Taut $\dfrac{}{\varphi}$ if φ is an instance of a prop-logic tautology

Modus Ponens $\dfrac{\varphi \quad \varphi \supset \varphi'}{\varphi'}$ *Says* $\dfrac{\varphi}{P \text{ says } \varphi}$

MP Says $\dfrac{}{(P \text{ says } (\varphi \supset \varphi')) \supset (P \text{ says } \varphi \supset P \text{ says } \varphi')}$

Speaks For $\dfrac{}{P \Rightarrow Q \supset (P \text{ says } \varphi \supset Q \text{ says } \varphi)}$

Quoting $\dfrac{}{P \mid Q \text{ says } \varphi \equiv P \text{ says } Q \text{ says } \varphi}$

& Says $\dfrac{}{P \,\&\, Q \text{ says } \varphi \equiv P \text{ says } \varphi \wedge Q \text{ says } \varphi}$

Idempotency of $\Rightarrow$ $\dfrac{}{P \Rightarrow P}$

Monotonicity of $\mid$ $\dfrac{P' \Rightarrow P \quad Q' \Rightarrow Q}{P' \mid Q' \Rightarrow P \mid Q}$

Associativity of $\mid$ $\dfrac{P \mid (Q \mid R) \text{ says } \varphi}{(P \mid Q) \mid R \text{ says } \varphi}$

$$P \text{ controls } \varphi \stackrel{\text{def}}{=} (P \text{ says } \varphi) \supset \varphi$$

$$P \text{ reps } Q \text{ on } \varphi \stackrel{\text{def}}{=} P \mid Q \text{ says } \varphi \supset Q \text{ says } \varphi$$

Examples

A simple proof

1.	P controls φ	Assumption
2.	P says φ	Assumption
3.	P says $\varphi \supset \varphi$	1 def'n controls
4.	φ	2, 3 Modus Ponens

Derived inference rule

$$\textit{Controls} \quad \frac{P \text{ controls } \varphi \qquad P \text{ says } \varphi}{\varphi}$$

All derived rules are sound

In HOL

Controls Proof

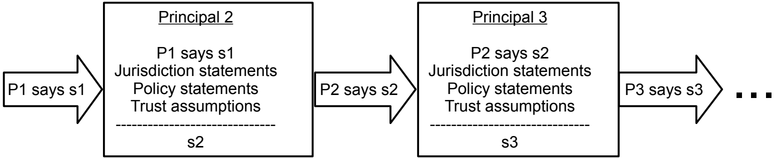
```
- val a1 = ACL_ASSUM ``(P:'c Princ) controls (f:('a,'c,'d,'e)Form)``;
> val a1 =  [.] |- (M,Oi,Os) sat P controls f : thm
- val a2 = ACL_ASSUM ``(P:'c Princ) says (f:('a,'c,'d,'e)Form)``;
> val a2 =  [.] |- (M,Oi,Os) sat P says f : thm
- val th3 = REWRITE_RULE [Controls_Eq] a1;
> val th3 =  [.] |- (M,Oi,Os) sat P says f impf f : thm
- val th4 = ACL_MP a2 th3;
> val th4 =  [..] |- (M,Oi,Os) sat f : thm
- val th5 =
       GENL [``(M :('a, 'b, 'c, 'd, 'e) Kripke)``,``(Oi :'d po)``,``(Os :'e po)``,
             ``(P :'c Princ)``,``(f :('a, 'c, 'd, 'e) Form)``]
             (DISCH_ALL th4);
> val th5 =
    |- ∀M Oi Os P f.
         (M,Oi,Os) sat P says f ⇒
         (M,Oi,Os) sat P controls f ⇒
         (M,Oi,Os) sat f : thm
-
```

Controls Inference Rule

```
(************************************************************
* CONTROLS
*
* CONTROLS : thm->thm -> thm
*
* SYNOPSIS
* Deduces formula f if the principal who says f also controls f.
*
* DESCRIPTION
*
*     A1 |- (M,Oi,Os) sat P controls f   A2 |- (M,Oi,Os) sat P says f
*     ----------------------------------------------------------  CONTROLS
*                        A1 u A2 |- (M,Oi,Os) sat f
*
* FAILURE
* Fails unless the theorems match in terms of principals and formulas
* in the access-control logic.
************************************************************)
fun CONTROLS th1 th2 = MATCH_MP (MATCH_MP (SPEC_ALL Controls) th2) th1;
```

General Form of CONOPS

"The CONOPS ... describes how the actions of ... components and supporting organizations will be integrated, synchronized, and phased to accomplish the mission ..."



- Principals are actors
- Assumptions about jurisdiction, policy, and trust are explicit
- Each step in CONOPS is a derived inference rule

Example: A (Hypothetical) Kill Chain

Joint Terminal Air Controller

$\Longleftrightarrow$

Airborne Early Warning & Control

$\Updownarrow$ $\swarrow\nearrow$ $\Updownarrow$

Remotely Piloted Vehicle

$\Longleftrightarrow$

Air Operations Center

Example: A (Hypothetical) Kill Chain

$\Longleftrightarrow$

Joint Terminal Air Controller

Airborne Early Warning & Control

$\Updownarrow$ $\swarrow\nearrow$ $\Updownarrow$

$\Longleftrightarrow$

Remotely Piloted Vehicle

Air Operations Center

Example: A (Hypothetical) Kill Chain

$\Longleftrightarrow$

Joint Terminal Air Controller

Airborne Early Warning & Control

$\Updownarrow$ $\swarrow \nearrow$ $\Updownarrow$

$\Longleftrightarrow$

Remotely Piloted Vehicle

Air Operations Center

Example: A (Hypothetical) Kill Chain

Joint Terminal Air Controller

$\Longleftrightarrow$

Airborne Early Warning & Control

$\Updownarrow$ $\swarrow\nearrow$ $\Updownarrow$

Remotely Piloted Vehicle

$\Longleftrightarrow$

Air Operations Center

Example: A (Hypothetical) Kill Chain

$\Longleftrightarrow$

Joint Terminal Air Controller

Airborne Early Warning & Control

$\Updownarrow$ $\swarrow\nearrow$ $\Updownarrow$

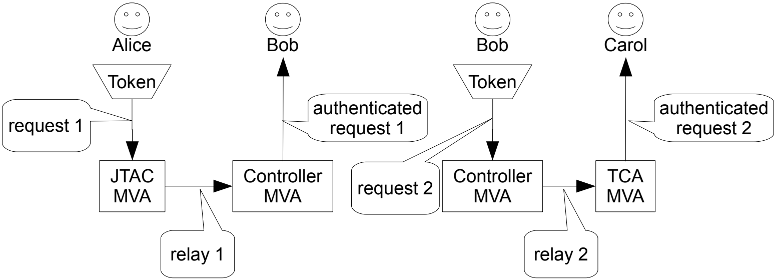
$\Longleftrightarrow$

Remotely Piloted Vehicle

Air Operations Center

Hypothetical CONOPS

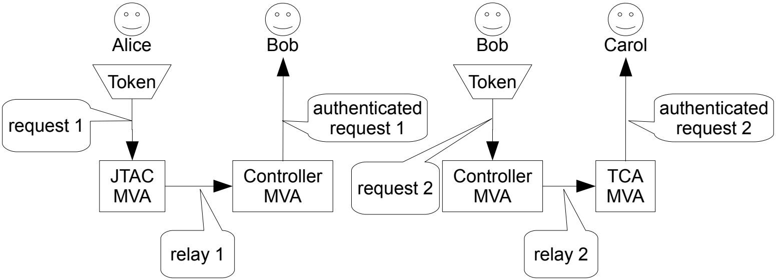
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target \rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target \rangle$
authenticated request 1	$JTAC$ says $\langle strike, target \rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target \rangle)$

Hypothetical CONOPS

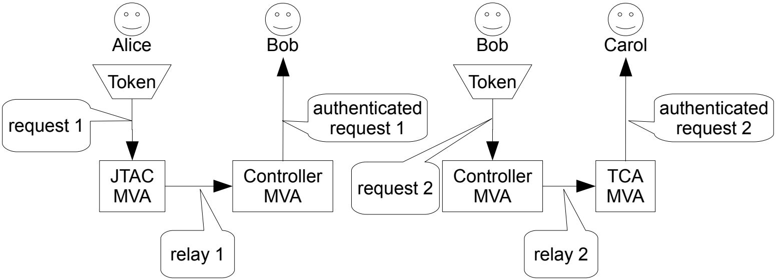
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target\rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target\rangle$
authenticated request 1	$JTAC$ says $\langle strike, target\rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target\rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target\rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target\rangle)$

Hypothetical CONOPS

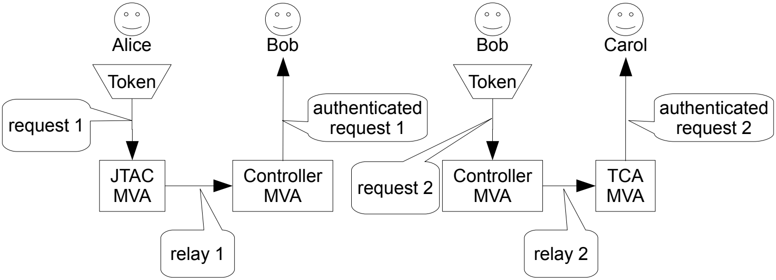
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target \rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target \rangle$
authenticated request 1	$JTAC$ says $\langle strike, target \rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target \rangle)$

Hypothetical CONOPS

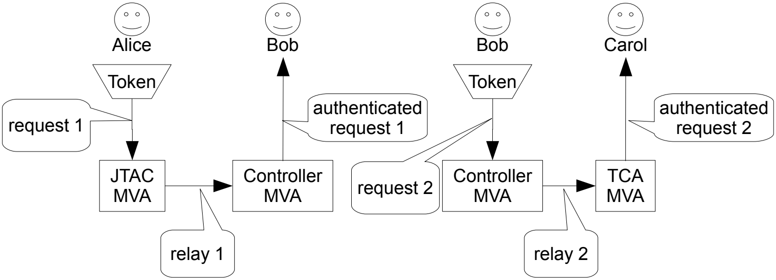
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target \rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target \rangle$
authenticated request 1	$JTAC$ says $\langle strike, target \rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target \rangle)$

Hypothetical CONOPS

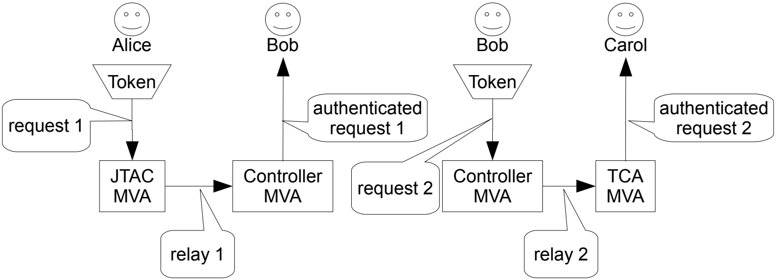
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target\rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target\rangle$
authenticated request 1	$JTAC$ says $\langle strike, target\rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target\rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target\rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target\rangle)$

Hypothetical CONOPS

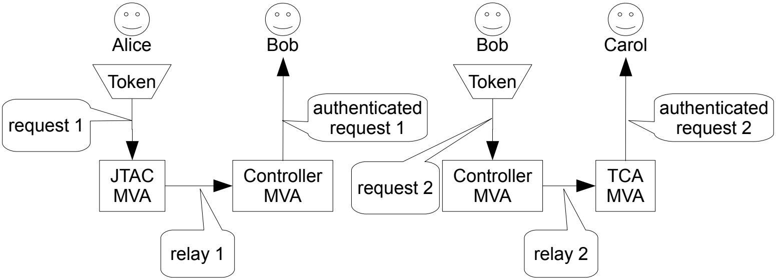
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target \rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target \rangle$
authenticated request 1	$JTAC$ says $\langle strike, target \rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target \rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target \rangle)$

Hypothetical CONOPS

All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



Statement	Formal Representation
request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target\rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target\rangle$
authenticated request 1	$JTAC$ says $\langle strike, target\rangle$
request 2	$(Token_{Bob} \mid Controller)$ says $(JTAC$ says $\langle strike, target\rangle)$
relay 2	$(K_{Controller\text{-}MVA} \mid Controller)$ says $(JTAC$ says $\langle strike, target\rangle)$
authenticated request 2	$Controller$ says $(JTAC$ says $\langle strike, target\rangle)$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA
:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA

:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA
:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(Token\ or\ Key \mid Role)$ says φ
Delegation Cert	K_{Auth} says $(Person\ or\ Object$ reps $Role$ on $\varphi)$
Key Certificate	K_{Auth} says $(Token\ or\ Key \Rightarrow Person\ or\ Object)$
Jurisdiction	$Auth$ controls $(Person\ or\ Object$ reps $Role$ on $\varphi)$
Jurisdiction	$Auth$ controls $(Token\ or\ Key \Rightarrow Person\ or\ Object)$
Trust Assumption	$K_{Auth} \Rightarrow Auth$

Transmitting MVA:

$$\text{MVA 1}\ \frac{\begin{array}{c}(Token \mid Role)\ \text{says}\ \varphi \\ K_{Auth}\ \text{says}\ (Person\ \text{reps}\ Role\ \text{on}\ \varphi) \\ K_{Auth}\ \text{says}\ (Token \Rightarrow Person) \\ Auth\ \text{controls}\ (Person\ \text{reps}\ Role\ \text{on}\ \varphi) \\ Auth\ \text{controls}\ (Token \Rightarrow Person) \\ K_{Auth} \Rightarrow Auth\end{array}}{K_{MVA_1} \mid Role\ \text{says}\ \varphi}$$

Receiving MVA
:

$$\text{MVA 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid Role)\ \text{says}\ \varphi \\ K_{Auth}\ \text{says}\ (MVA_1\ \text{reps}\ Role\ \text{on}\ \varphi) \\ K_{Auth}\ \text{says}\ (K_{MVA_1} \Rightarrow MVA_1) \\ Auth\ \text{controls}\ (MVA_1\ \text{reps}\ Role\ \text{on}\ \varphi) \\ Auth\ \text{controls}\ (K_{MVA_1} \Rightarrow MVA_1) \\ K_{Auth} \Rightarrow Auth\end{array}}{Role\ \text{says}\ \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA
:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA

:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{\mathit{Auth}} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{\mathit{Auth}} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{\mathit{Auth}} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{\mathit{Auth}} \Rightarrow \mathit{Auth}\end{array}}{K_{\mathit{MVA}_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA
:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{\mathit{MVA}_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{\mathit{Auth}} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{\mathit{Auth}} \text{ says } (K_{\mathit{MVA}_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{\mathit{MVA}_1} \Rightarrow \mathit{MVA}_1) \\ K_{\mathit{Auth}} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\textit{MVA 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA

:

$$\textit{MVA 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA
:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\ \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA

:

$$\mathit{MVA\ 2}\ \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

Repeated Pattern of Authentication and Trust

Common *form* of requests, delegations, key certificates, jurisdiction, and trust assumptions

Input	$(\mathit{Token\ or\ Key} \mid \mathit{Role})$ says φ
Delegation Cert	K_{Auth} says $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Key Certificate	K_{Auth} says $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Jurisdiction	Auth controls $(\mathit{Person\ or\ Object}$ reps Role on $\varphi)$
Jurisdiction	Auth controls $(\mathit{Token\ or\ Key} \Rightarrow \mathit{Person\ or\ Object})$
Trust Assumption	$K_{Auth} \Rightarrow \mathit{Auth}$

Transmitting MVA:

$$\mathit{MVA\ 1}\quad \frac{\begin{array}{c}(\mathit{Token} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (\mathit{Token} \Rightarrow \mathit{Person}) \\ \mathit{Auth} \text{ controls } (\mathit{Person} \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (\mathit{Token} \Rightarrow \mathit{Person}) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{K_{MVA_1} \mid \mathit{Role} \text{ says } \varphi}$$

Receiving MVA
:

$$\mathit{MVA\ 2}\quad \frac{\begin{array}{c}(K_{MVA_1} \mid \mathit{Role}) \text{ says } \varphi \\ K_{Auth} \text{ says } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ K_{Auth} \text{ says } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ \mathit{Auth} \text{ controls } (\mathit{MVA}_1 \text{ reps } \mathit{Role} \text{ on } \varphi) \\ \mathit{Auth} \text{ controls } (K_{MVA_1} \Rightarrow \mathit{MVA}_1) \\ K_{Auth} \Rightarrow \mathit{Auth}\end{array}}{\mathit{Role} \text{ says } \varphi}$$

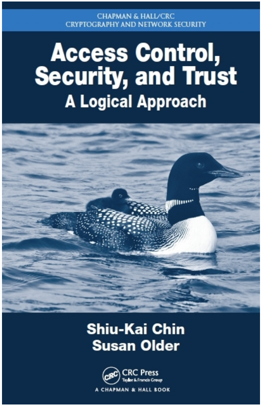
Findings & Conclusions

226+ ACE cadets, captains, & lieutenants from 40+ universities

Formal approach to access control and CONOPS is feasible (with adequate education)

- 21 hours of instruction
- Kripke semantics, basic & distributed access control, delegation, hardware, and confidentiality/integrity policies

Textbook based on access-control logic taught in ACE



Increased their capabilities to design, specify, evaluate, and procure critical systems