Policy-Based Design and Verification for Mission Assurance

Shiu-Kai Chin[1], Sarah Muccio[2], Susan Older[1], and Thomas Vestal[1,2]
[1] *Syracuse University, Syracuse, New York*
[2] *Air Force Research Laboratory, Rome, New York*

Why Trust and Assurance Matter

"That is, the pilot can trust information that a target is the foe, not innocent inhabitants of a school building or hospital or embassy. . . . **This new way of war is data dependent. So we need to think in terms of trust and securing trust.**"

Michael Wynne, Former SECAF

"No operator should ever have to ask . . . 'Will my weapon work?' . . . Cyberspace warfare creates just this possibility."

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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)

Designers who sleep well combine experience with math & logic

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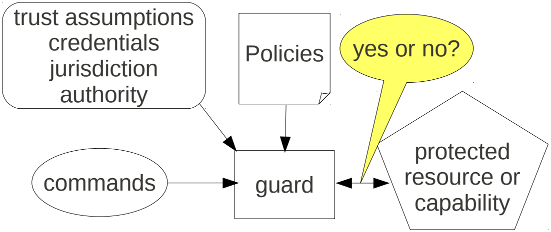

When given a command/request, trust assumptions, credentials, jurisdiction, authority, and policy

- Logically justify whether 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

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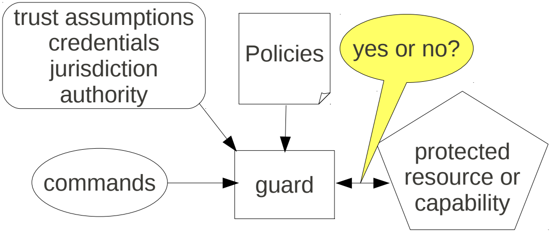

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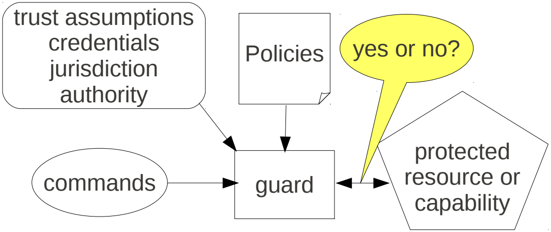

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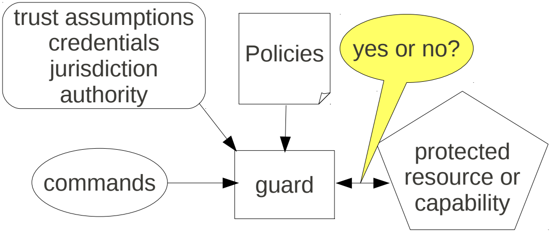

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A Logical Approach to Access Control

Access-control logic is used in the same way hardware engineers use propositional logic to specify, design, and verify hardware

- 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 5 theorem prover (joint work done with Lockwood Morris)
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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

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- Show how we describe and verify the logical consistency of CONOPS
- Show that the logic, proofs, and methods are well within the capabilities of practicing engineers
- Formally reasoning about CONOPS provides insight and precision into what is being relied upon, trust assumptions, policies, delegations, and flow of control

Preview

- Overview of the logic
- General representation of CONOPS
- A specific example
- Conclusions

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Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

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\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

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\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
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Semantics

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\mathcal{E}_\mathcal{M}[\![p]\!] &= I(p) \\
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Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

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Access-Control Logic Syntax & Semantics

Syntax

- Principals (actors)
- Statements they make

BNF

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

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Kripke structures

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

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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-5 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* $\dfrac{\varphi}{P \text{ says } \varphi}$

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

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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

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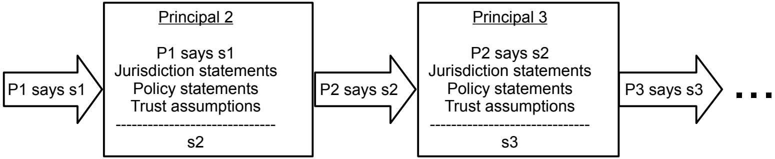
"The CONOPS ... describes how the actions of ... components and supporting organizations will be integrated, synchronized, and phased to accomplish the mission ..."



- Principals are actors
- Assumptions about jurisdiction, policy, and trust are explicit
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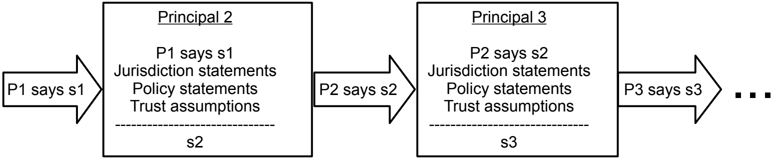

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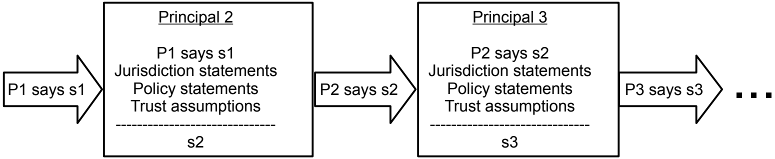

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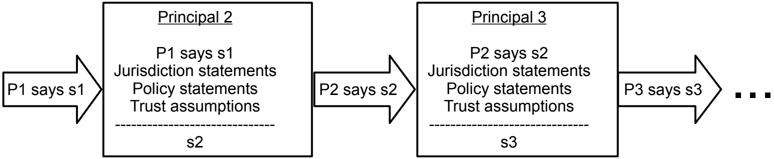

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Example: A (Hypothetical) Kill Chain

Joint Terminal Air Controller

$\Longleftrightarrow$

Airborne Early Warning & Control

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

Remotely Piloted Vehicle

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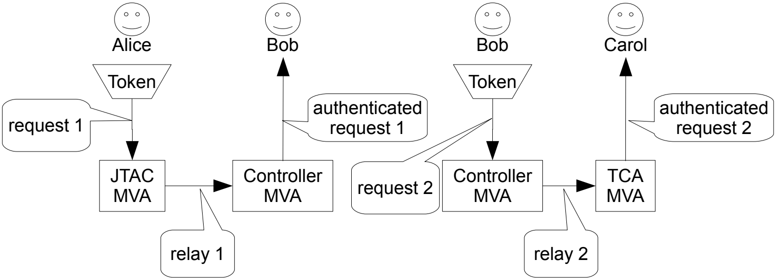
All personnel, roles, requests, and commands authenticated by a *Mission Validation Appliance (MVA)*.



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request 1	$(Token_{Alice} \mid JTAC)$ says $\langle strike, target \rangle$
relay 1	$(K_{JTAC\text{-}MVA} \mid JTAC)$ says $\langle strike, target \rangle$
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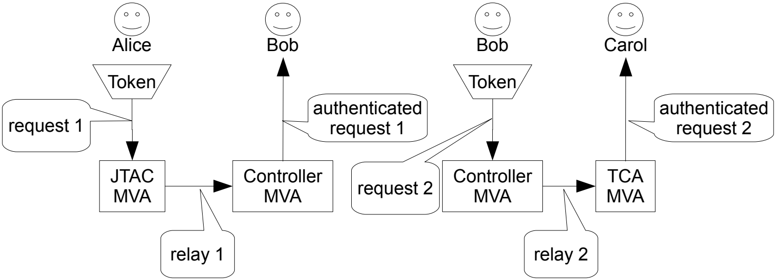

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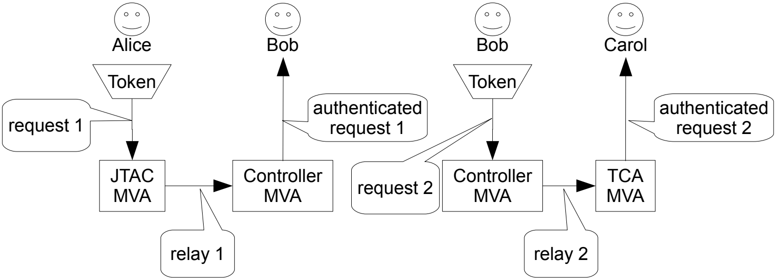

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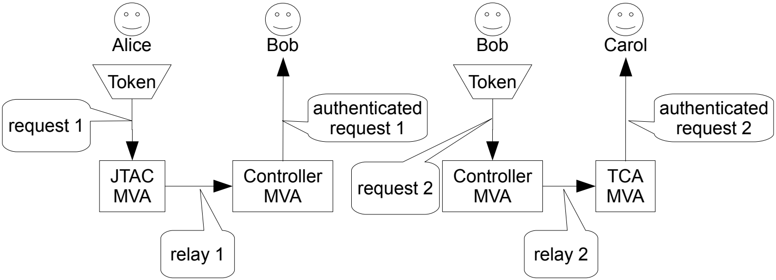

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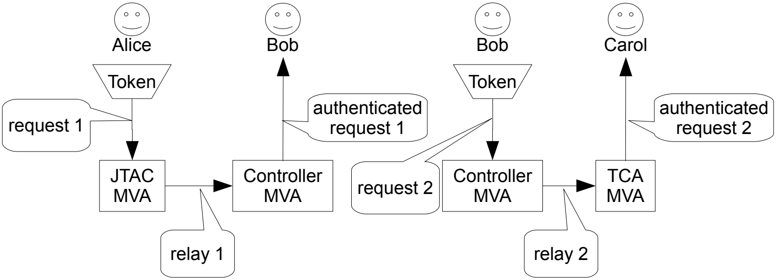

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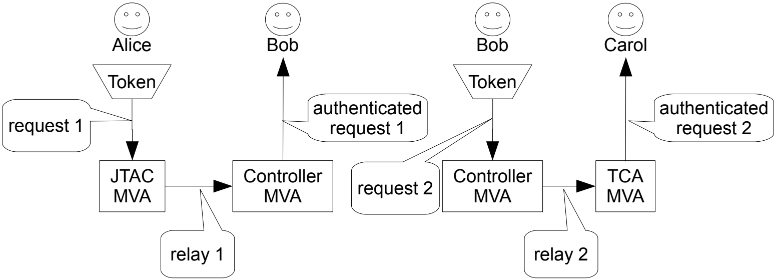

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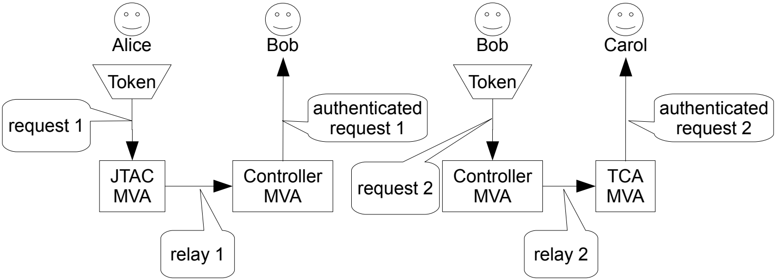

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Repeated Pattern of Authentication and Trust

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

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

Receiving MVA
:

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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 $\varphi)$
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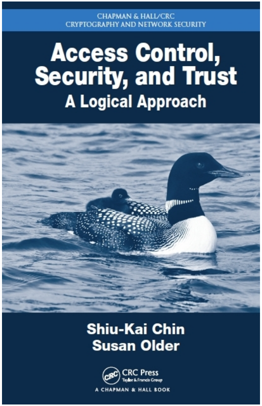
226+ ACE cadets, captains, & lieutenants from 40+ universities

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

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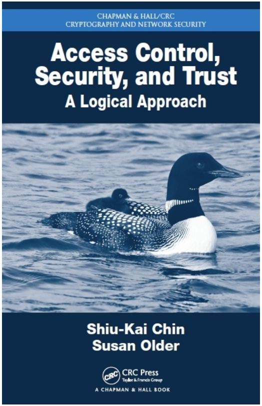

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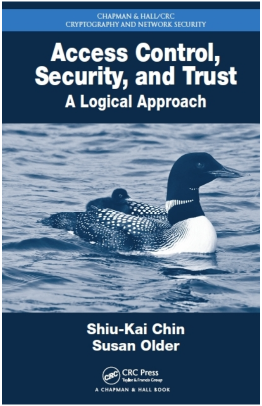

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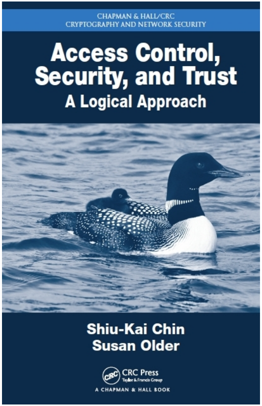

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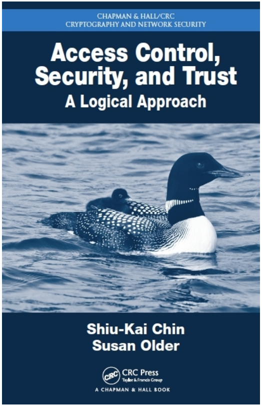

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