Center for Information Technology - IRST

SMT for Authorization
or
How Logic and Automated Reasoning can help securing your applications

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&

Who are I work (I): FBK Research Unit

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ST SECURITY & TRUST

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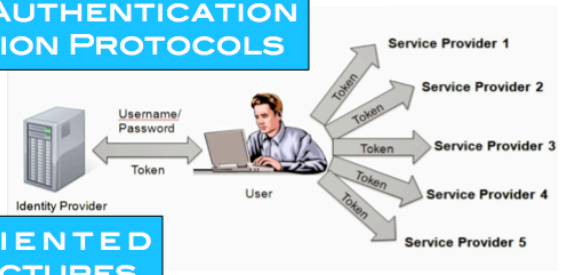
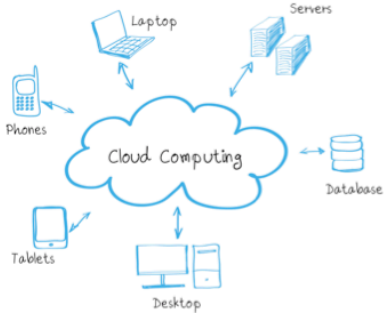
WEB-BASED AUTHENTICATION & AUTHORIZATION PROTOCOLS

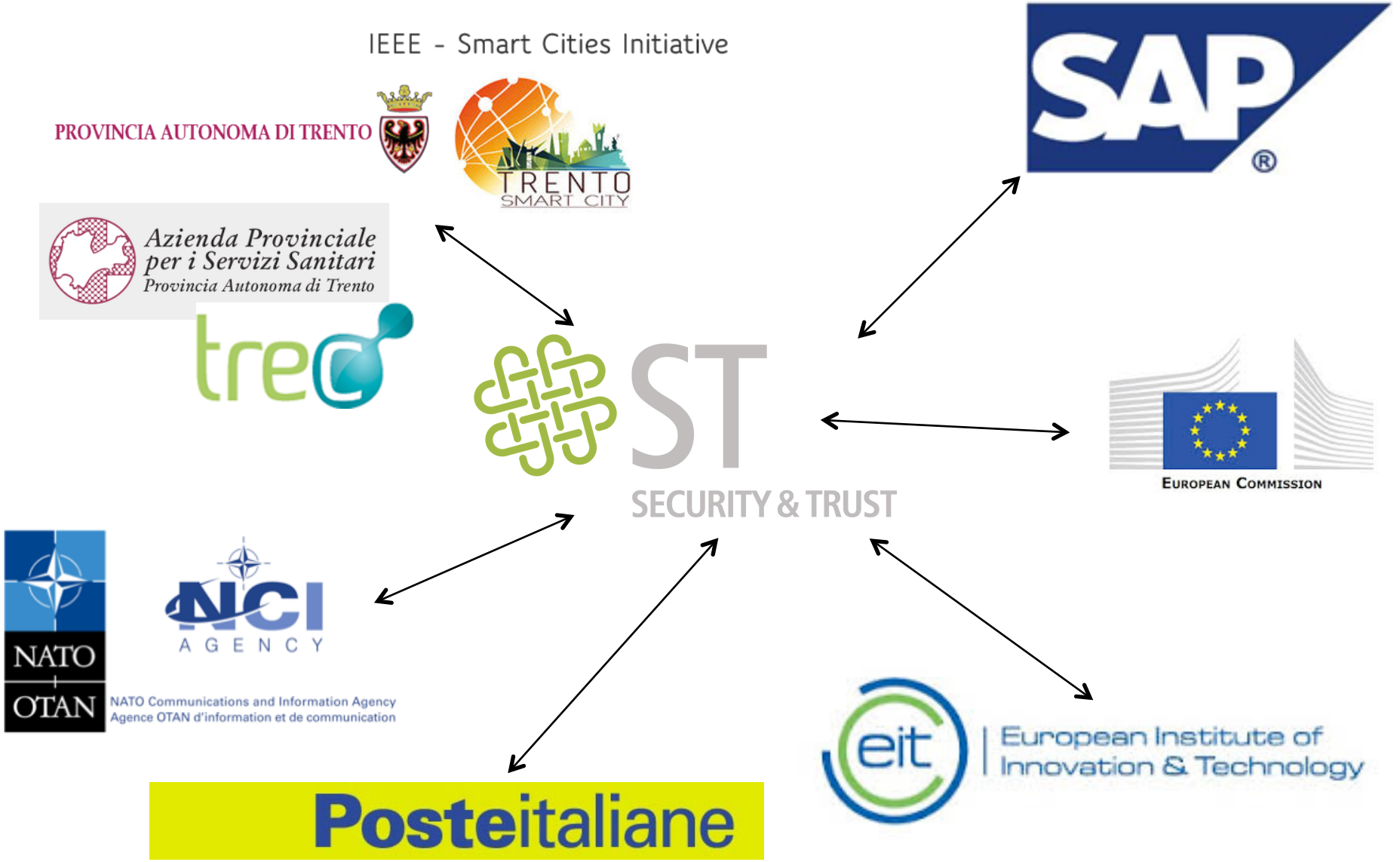


CLOUD & SERVICE-ORIENTED APPLICATIONS & INFRASTRUCTURES



MOBILE APPLICATIONS

Some Academic, PA, and Industrial collabs



Where I work (II): FBK-Poste Italiane joint lab

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Cyber Security Innovation Lab
Laboratorio di ricerca su tematiche di Cyber Security nato dalla collaborazione tra Poste Italiane e l'associazione Trento RISE.

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CSI Cyber Security Innovation Lab

Computer Emergency Response Team
Centro operativo di prevenzione e risposta agli incidenti informatici.

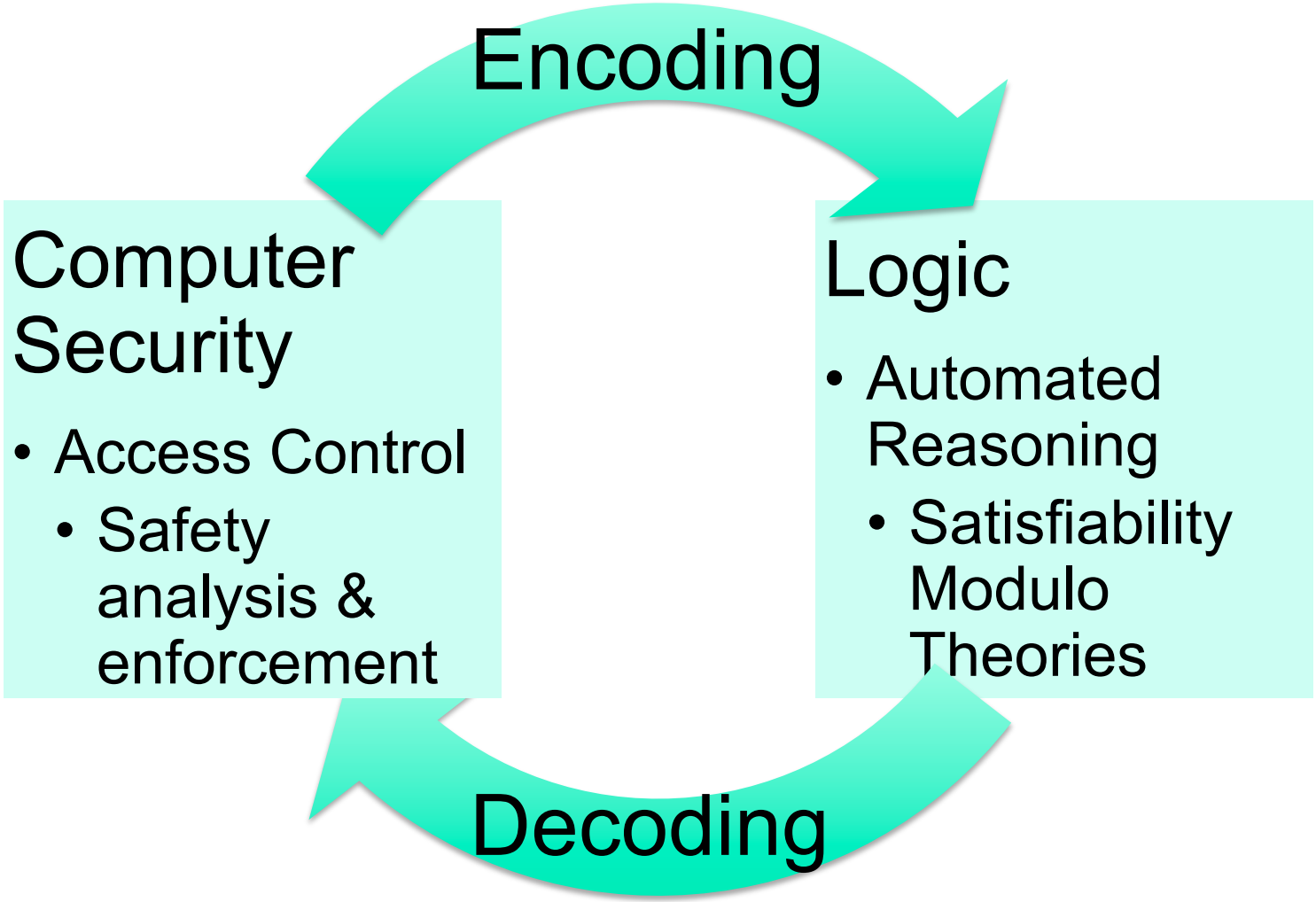
CERT Posteitaliane

Distretto di Cyber Security
Polo tecnologico per la ricerca industriale e lo sviluppo di soluzioni di sicurezza orientate alla protezione dell'end user, dei pagamenti elettronici e della dematerializzazione dei documenti. Nasce dal progetto PON finanziato dal MIUR.

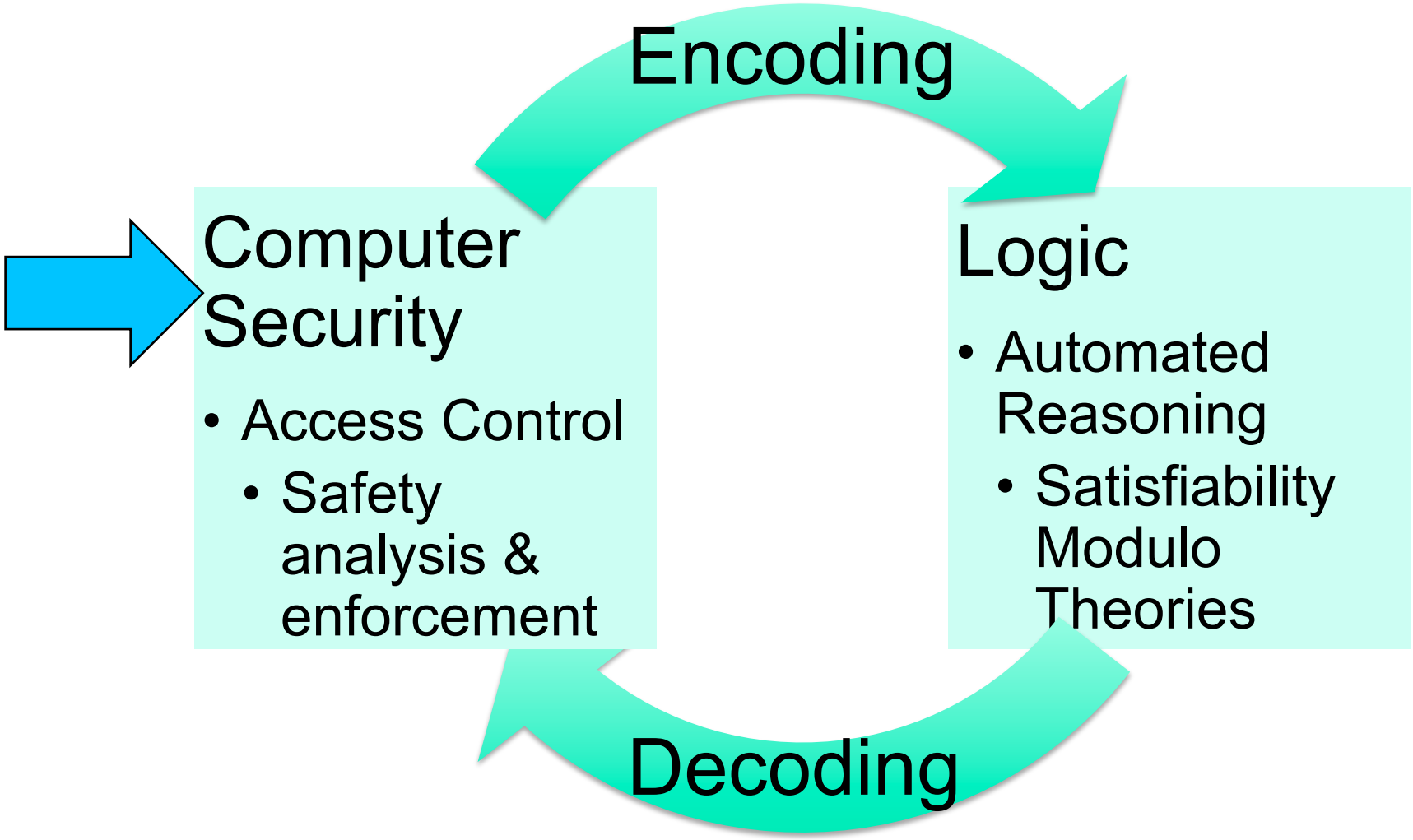
DCS Distretto Cyber Security

spid

This talk


Encoding
Computer Security
• Access Control
• Safety analysis & enforcement
Logic
• Automated Reasoning
• Satisfiability Modulo Theories
Decoding

Plan of the talk



Computer Security

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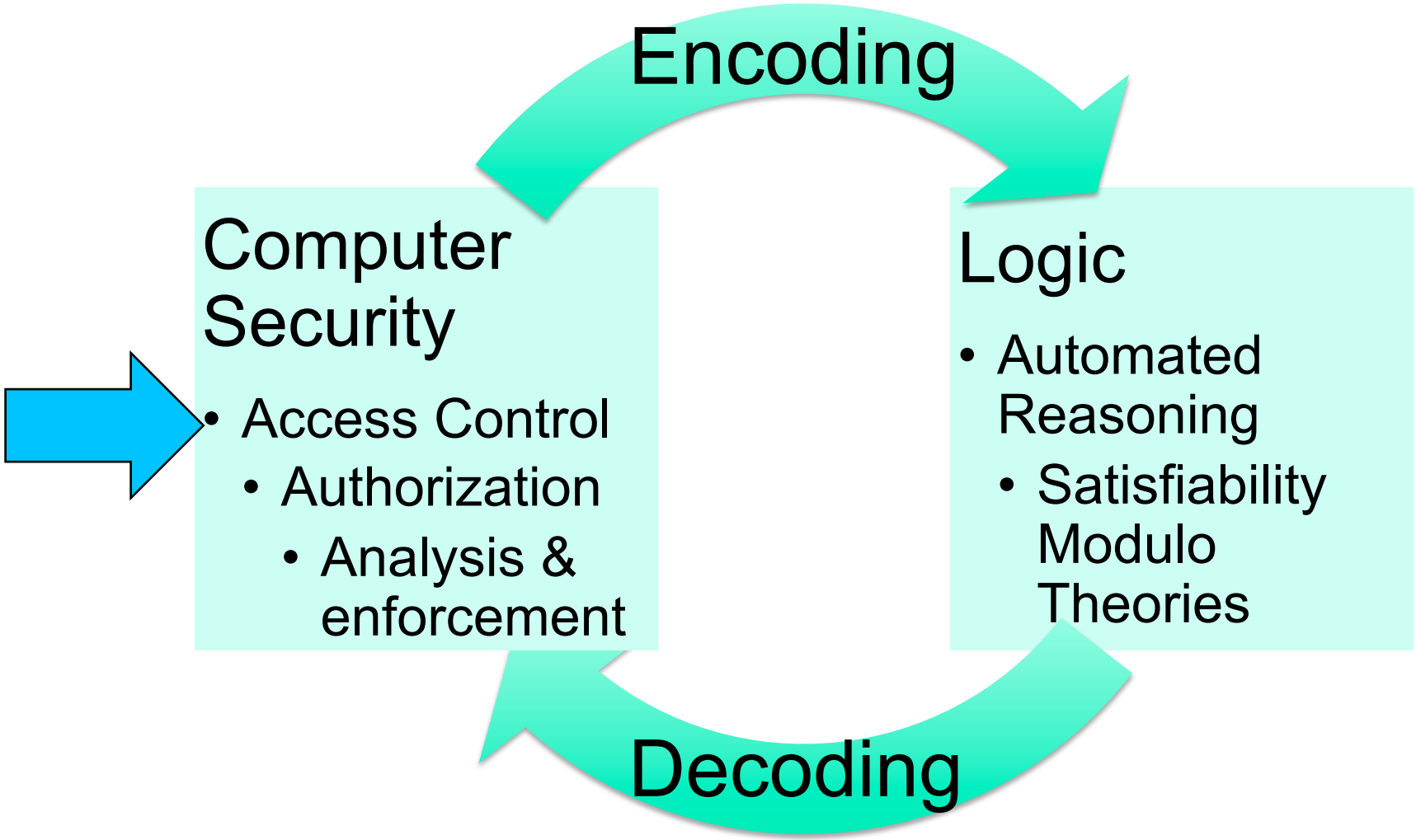
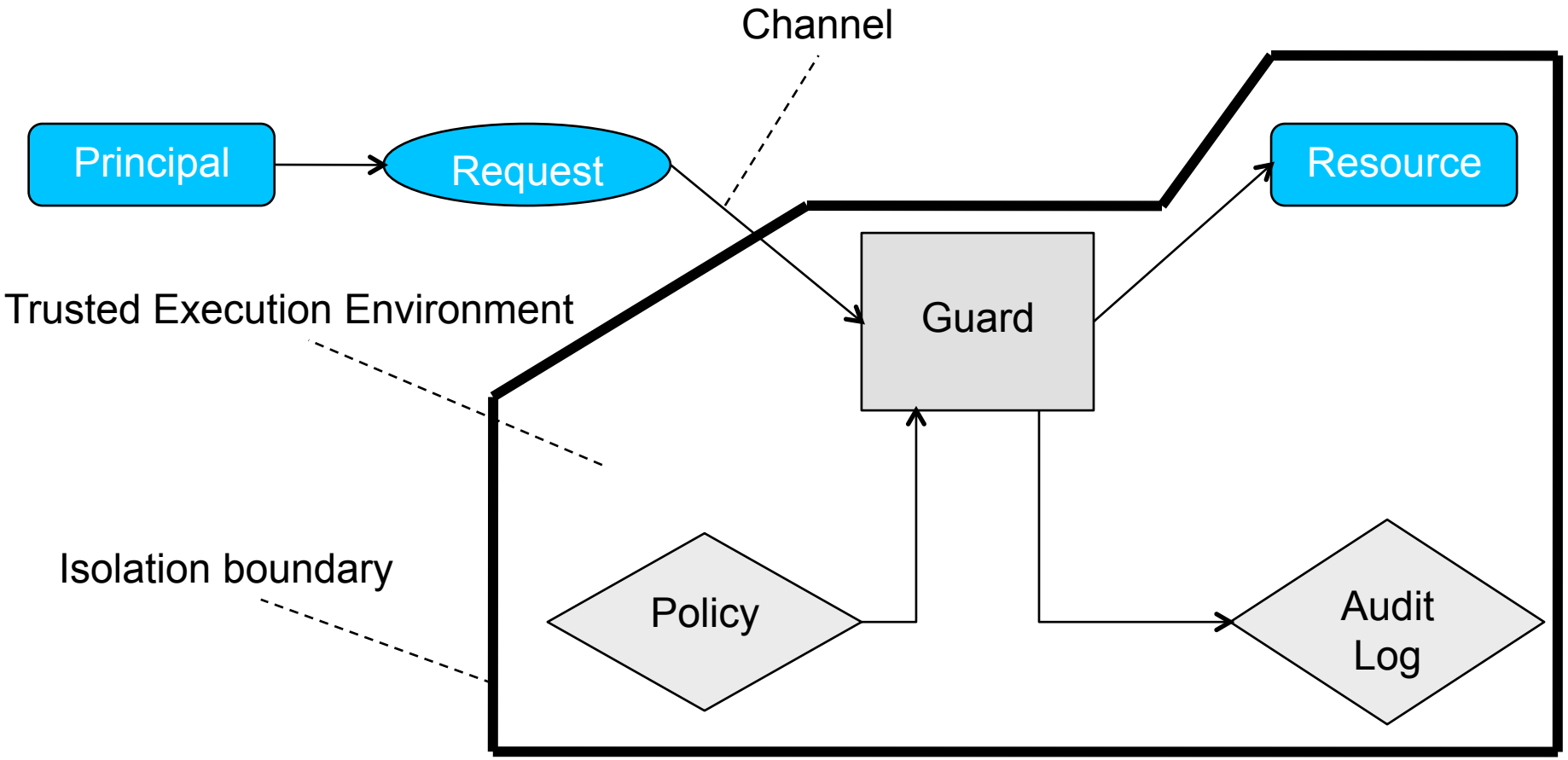
- Goal of Computer Security: to defend against vulnerabilities
  - 3 types of vulnerabilities
    - Bad (buggy/hostile) programs
    - Bad (careless/hostile) agents, programs or people, giving bad instructions to good but gullible programs
    - Bad agents tapping or spoofing communications
- 5 possible defense strategies
  - Isolate: keep everyone out (best security, impractical in most cases)
  - Exclude: keep bad guys out (e.g., firewalls)
  - Restrict: keep bad guys from doing damage (e.g., sanbox)
  - Recover: undo damages done by bad guys (e.g., backup)
  - Punish: catch & prosecute bad guys (e.g., auditing)

Plan of the talk

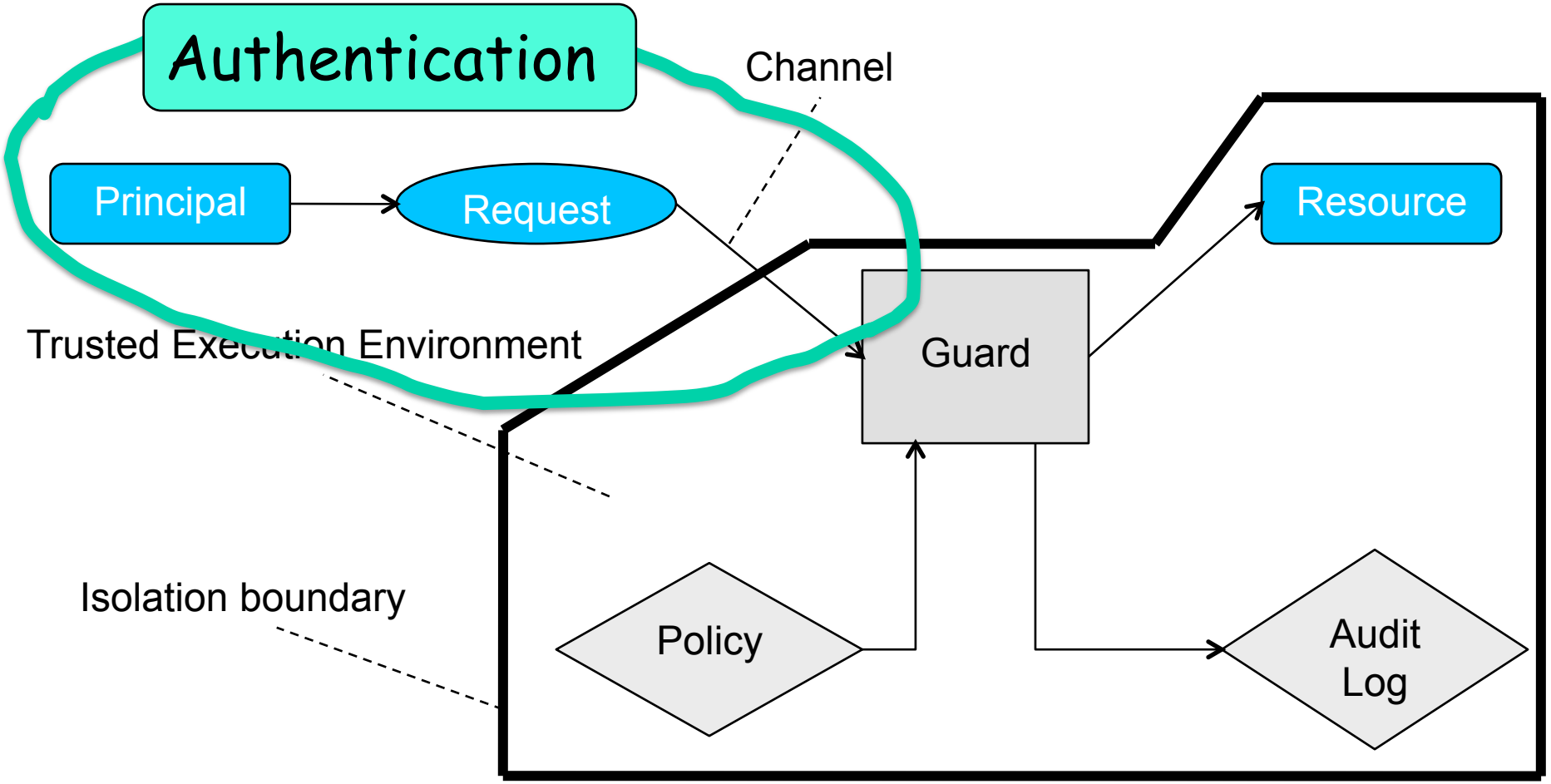


Access control



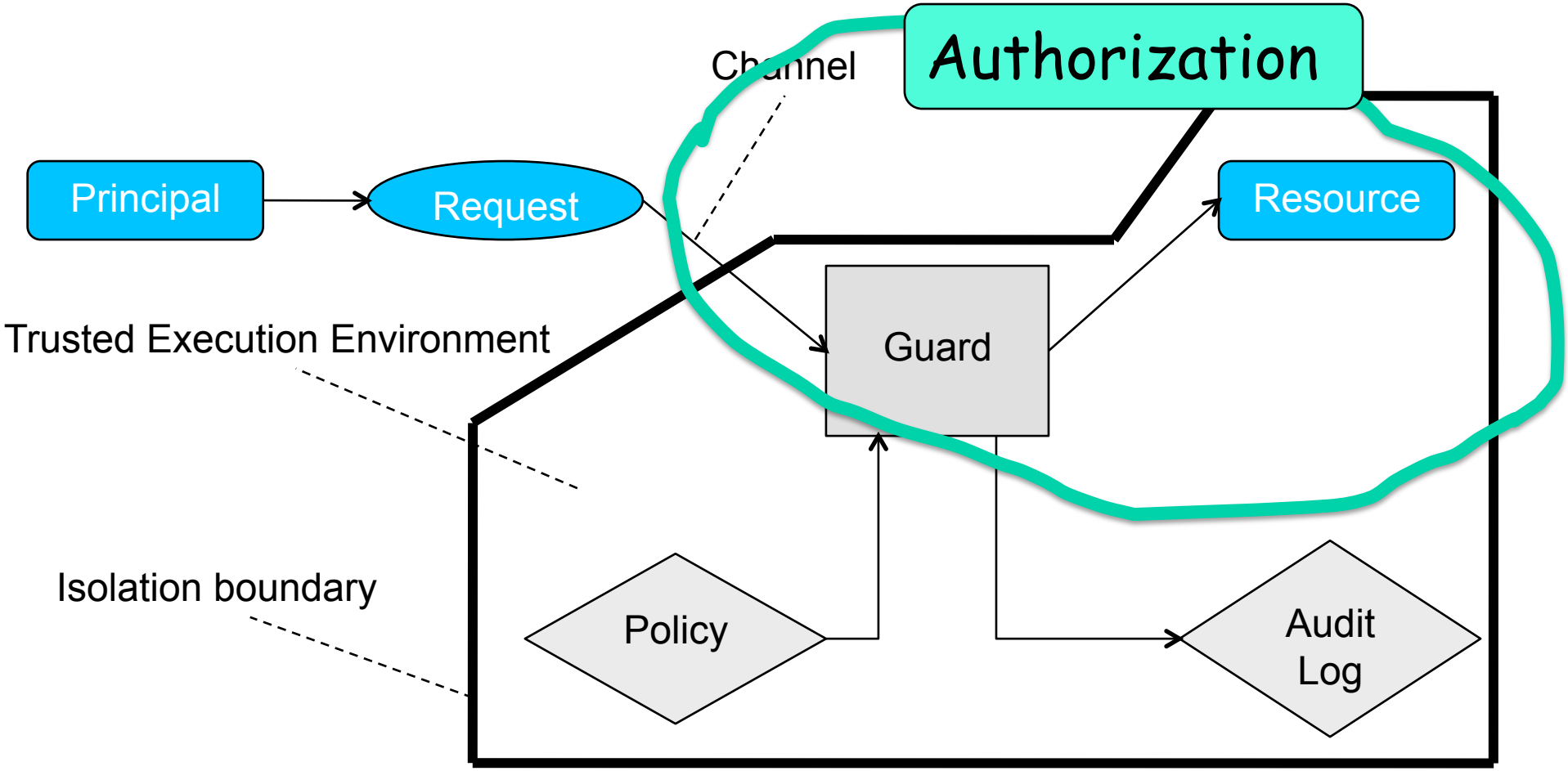
- Key security mechanism to implement 5 strategies above

Access control



- Key security mechanism to implement 5 strategies above

Access control



- Key security mechanism to implement 5 strategies above

AC = Authentication + Authorization + Auditing

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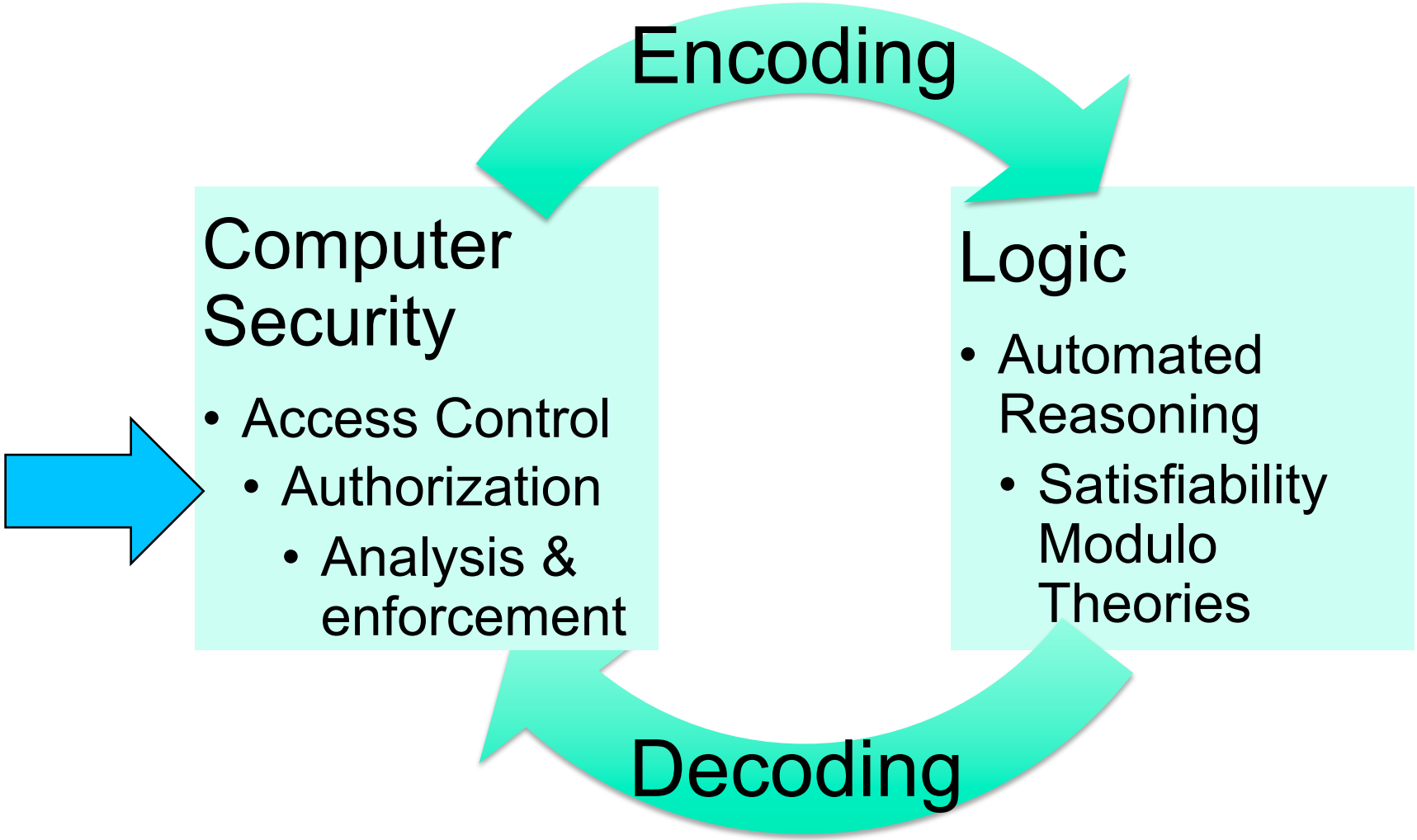
- Guard must decide whether the principal/subject (source of request) can do the operation on the resource/object
- To decide, guard uses
  - Authentication information = Who is getting info?
  - Authorization information = Who is trusted to do which operations on objects?
- Auditing = What happened and why?
- Crucial: the guard must see every request on object
  - Isolation boundary blocks all access to object except over the channel passing through the guard
- Policy = set of rules specifying conditions for principal to access resource based on features of principals, resources, and contextual information (e.g., time, location, …)

Plan of the talk



Authorization

- Authorization = Who is trusted to access a resource?
  - Confidentiality
    - Who can read the info stored in a resource?
  - Integrity
    - Who can write/update the info stored in a resource?
  - Availability
    - Are resources available when needed by trusted users?

- Note: boundary between authentication and authorization blurred, especially in modern applications

A framework for authorization

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Policy

- Rules specifying what actions principals may perform

Model

- Mathematical representation of the policy and its workings

Enforcement

- Low level (SW/HW) functions implementing control imposed by policy and formally stated in the model

Attribute Based Access Control (ABAC)

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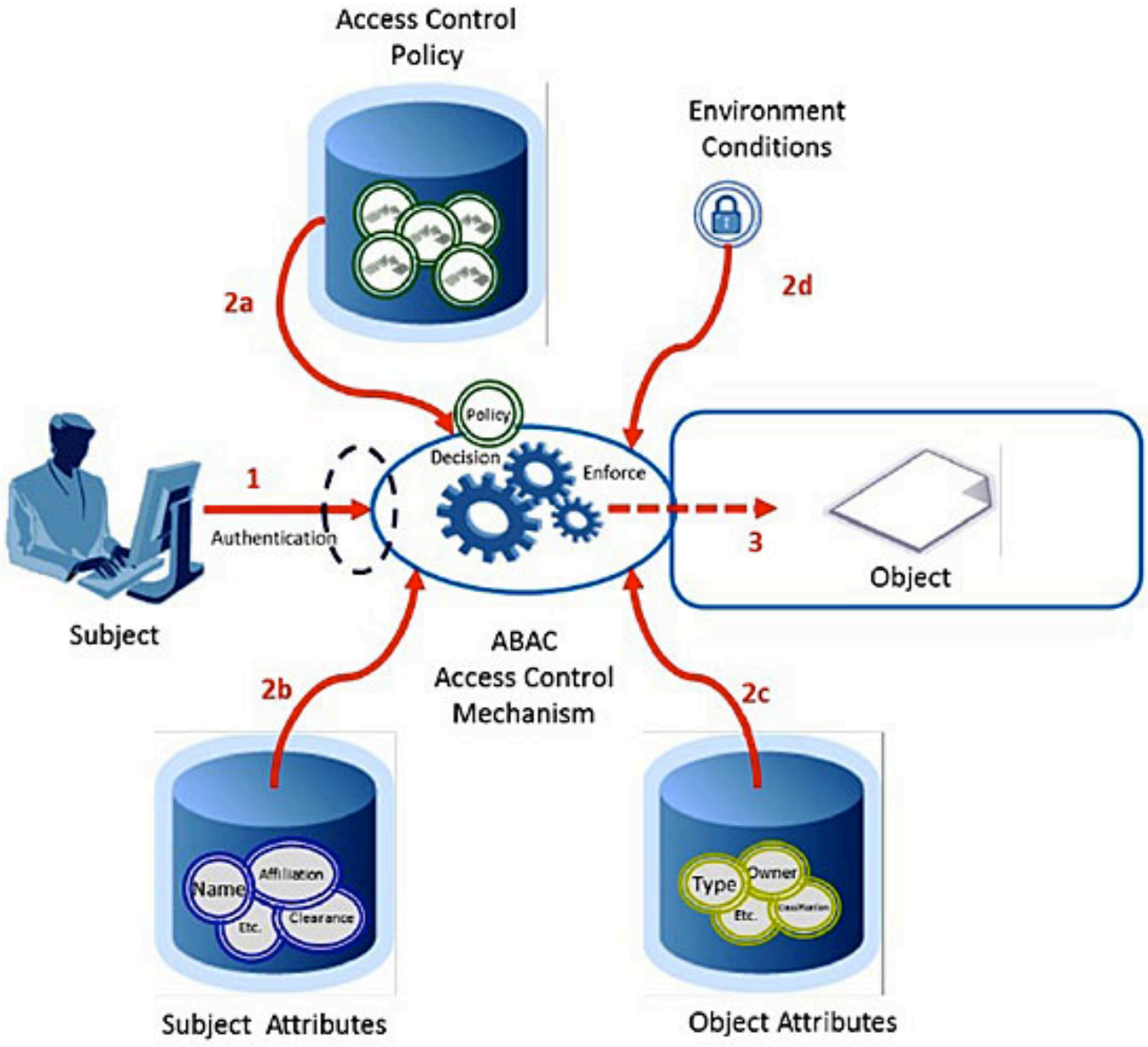
- Entities: Subjects, Actions, Objects, Environments
- Each entity has a set of attributes
  - Attribute = typed variable taking values on a domain
  - "e.a" is the attribute "a" of the entity "e"
- Attribute predicate = Boolean predicate on attributes
  - Can be specified by Boolean expressions on attributes and operators of the appropriate type, e.g.
    - Alice.Credit >= 100 & File.Classification = Secret
    - Alice.Credit >= Ebook.Value || …
- Policy = attribute predicate on the attributes of subject, action, object, and environment
- Request = list of pairs (attribute,value) for subject, action, object, and environment

ABAC: overview



ABAC: answering queries

- Policy P(s,a,o,e): predicate on attributes of s,a,o,e
- Query q=(s*,a*,o*,e*)
  - Encodes “Can s* perform a* on o* in e*?”
- Answering query q:

  “s* can perform a* on o* in e*” iff P(s*,a*,o*,e*) = TRUE
- Problem: which queries are allowed/denied by P?
- Problem: is a given set of queries allowed/denied by P?
- Problem: which queries are allowed/denied by two policies?
  - Difficult because policies can be specified by large & complex Boolean expressions
  - Answer should be found regardless of the enforcement mechanism

A framework for authorization

FONDAZIONE BRUNO KESSLER

Policy

- Rules specifying what actions principals may perform

Model

- Mathematical representation of the policy and its workings

Logical pbs, **independent of enforcement**

- Large number of rules
- Conditions depending on several features
- Evolving policies

A framework for authorization

Implementation pbs, **dependent from enforcement**

- Several technological scenarios
- Different security assumptions
- Authorization may depend on user device

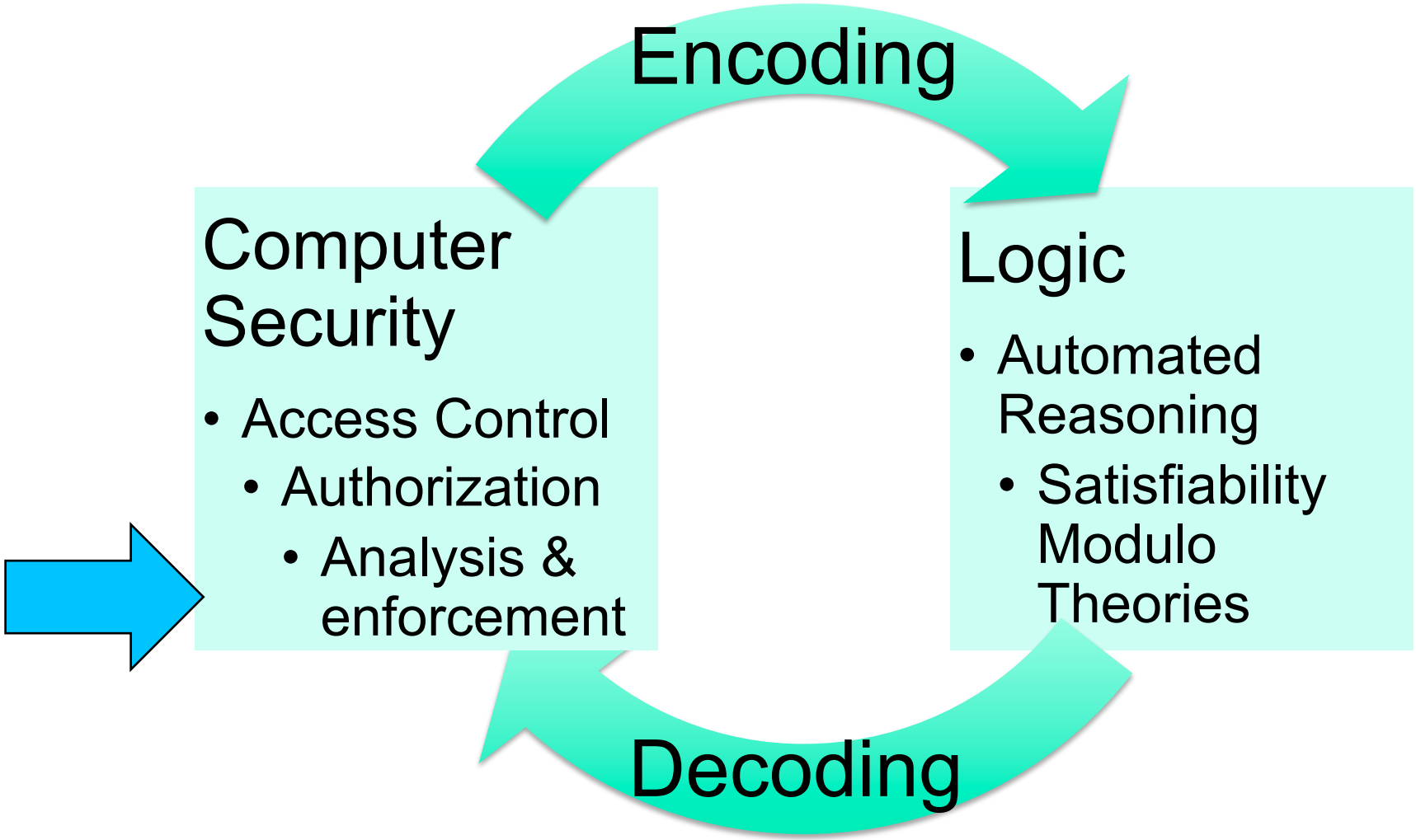
Model

- Mathematical representation of the policy and its workings

Enforcement

- Low level (SW/HW) functions implementing control imposed by policy and formally stated in the model

Plan of the talk

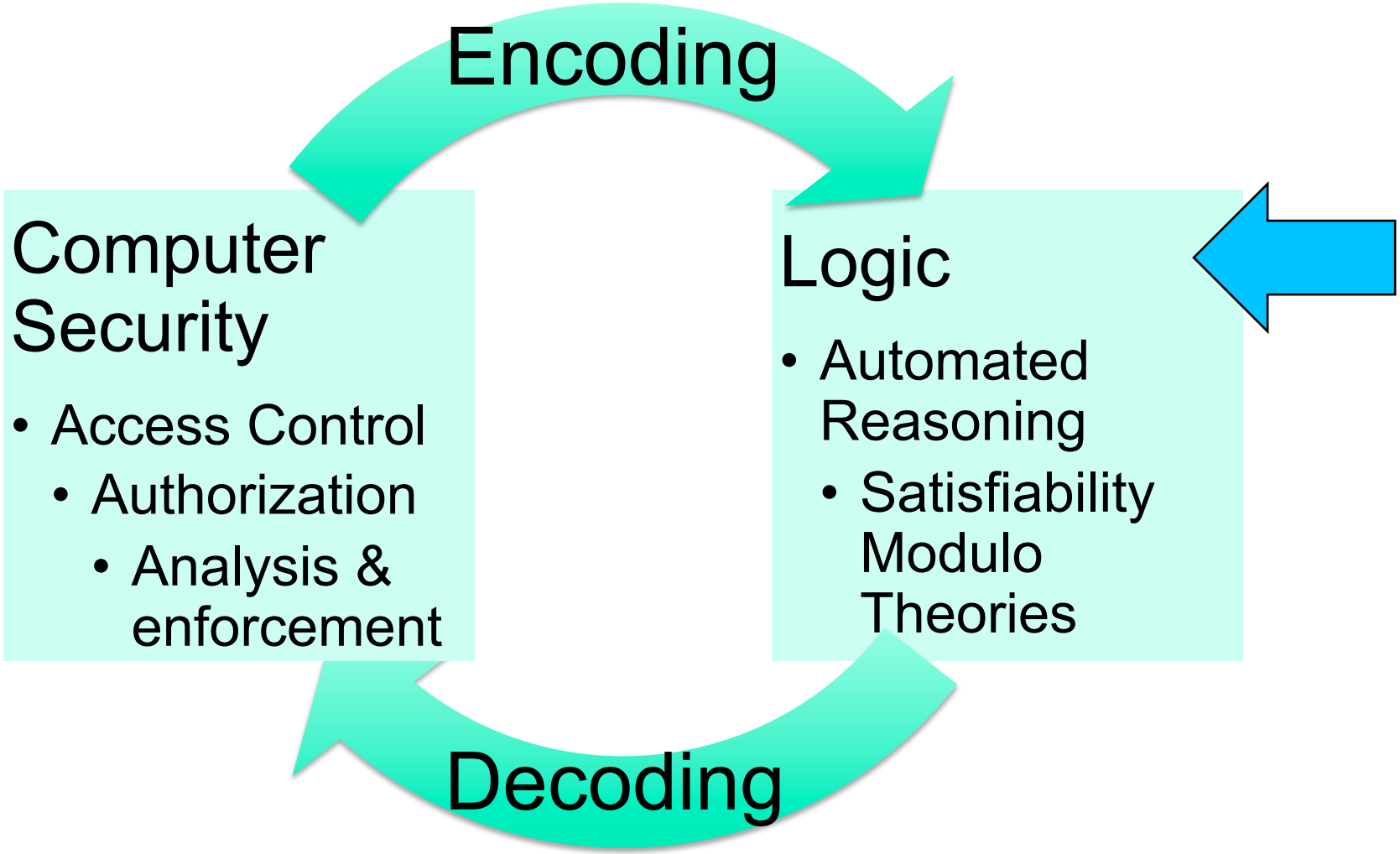


To get authorization right…

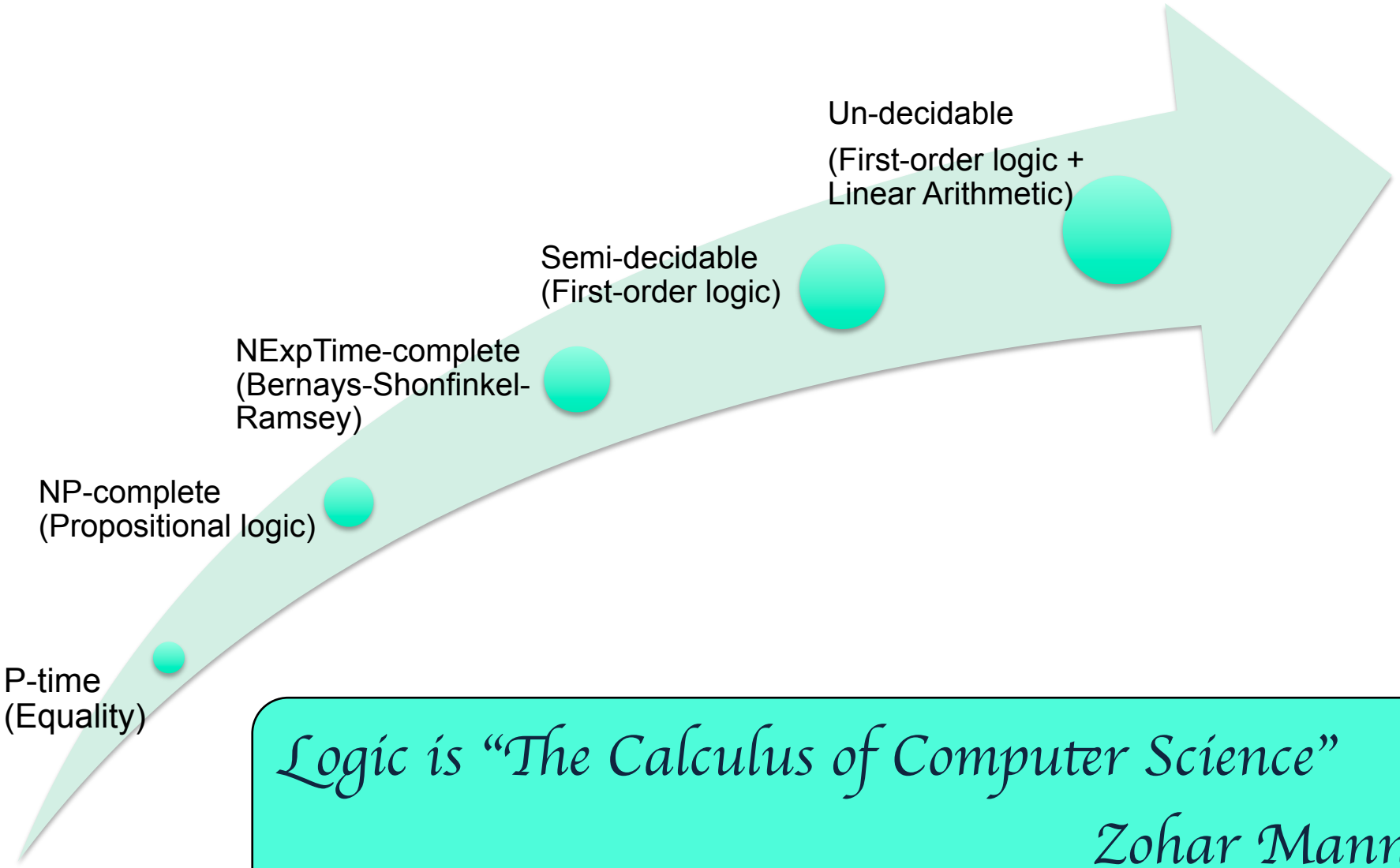
Need of automated techniques for

- Analysis @ design time for policy validation
  - scenarios, safety, …
  - change impact, refinement
- Enforcement @ deployment time for information sharing
  - from unique/coherent policy
  - in different technological scenarios and on different devices

Plan of the talk



Logic (First Order)



Logic is "The Calculus of Computer Science"

Zohar Manna

Problems in First Order Logic

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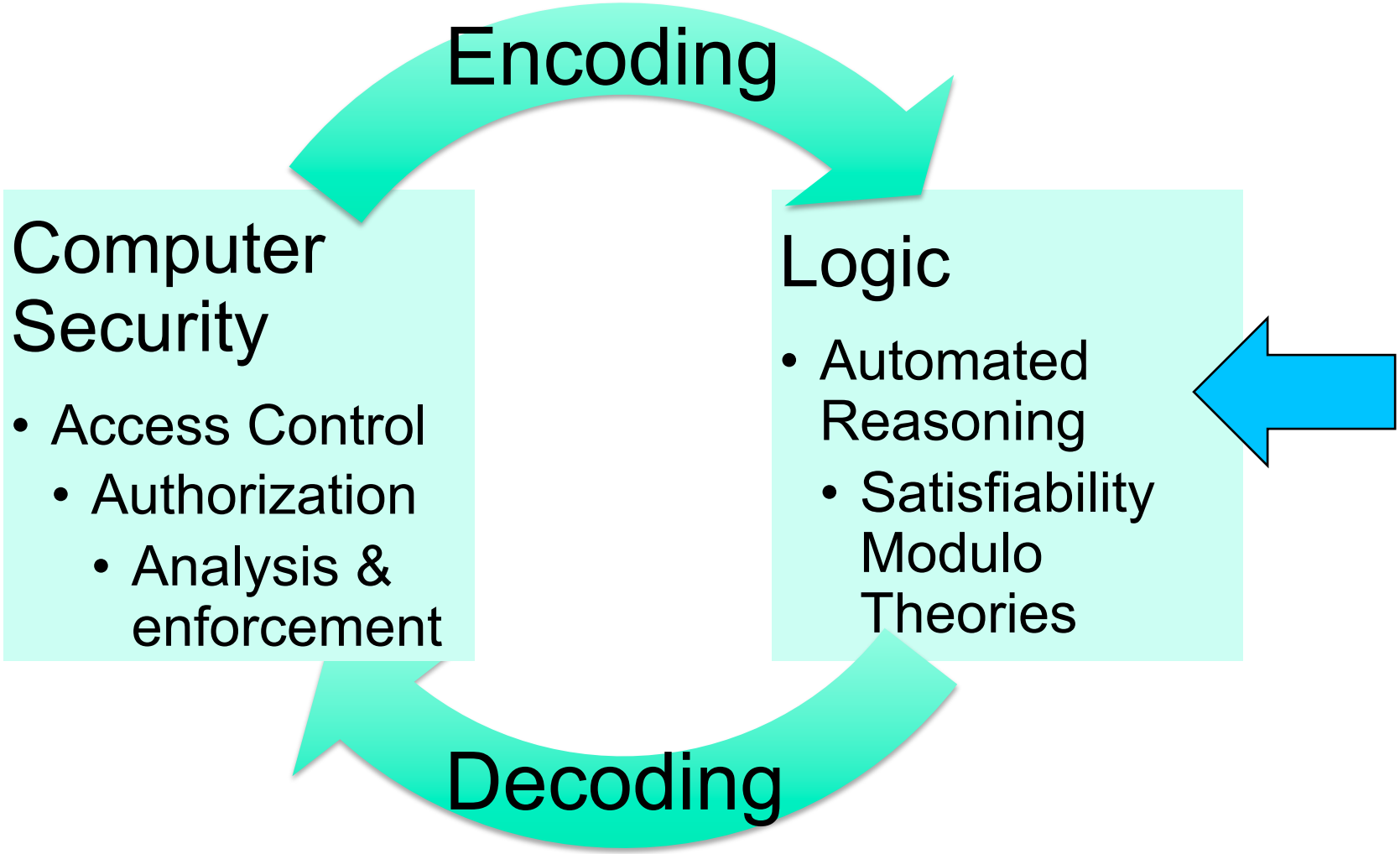
- Validity
  - Does formula φ hold in all models?
- Satisfiability
  - Is there a model in which formula φ holds?
- Formula φ is valid iff the negation of φ is unsatisfiable
- From now, we focus on satisfiability in FOL…

Plan of the talk



Automated Reasoning for **First Order Logic**

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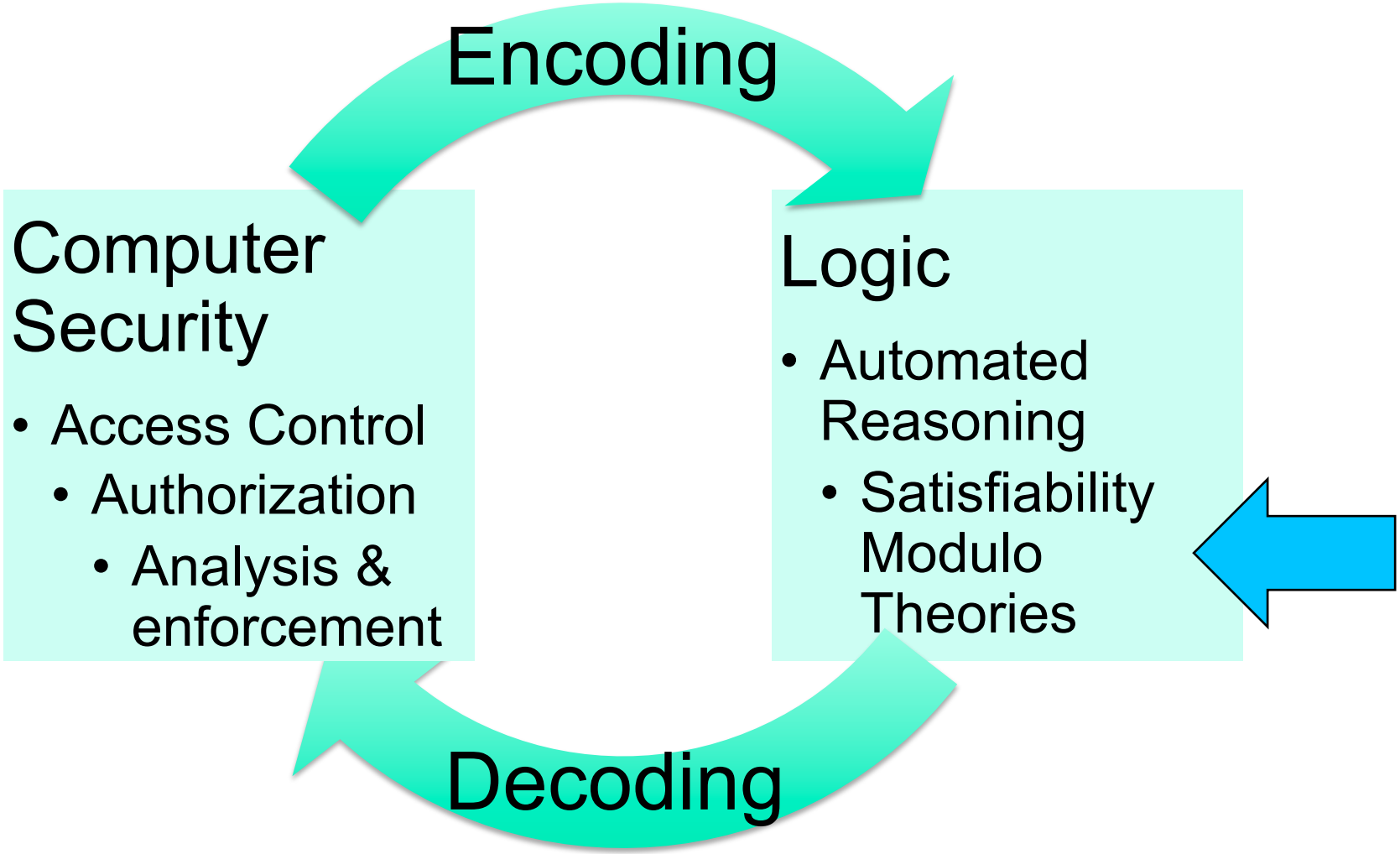
Expressivity

- Propositional
- Quantifier-free
- Quantifier prefix
- Full
- …

Decidability

- DPLL
- Resolution
- Decision procedures
- Quantifier instantiation & elimination
- Superposition
- …

Plan of the talk



Satisfiability Modulo Theories (SMT)

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- Satisfiability problem = determining whether a formula φ has a model
  - If φ is propositional, a model is a truth assignment to Boolean variables
  - If φ is a first-order formula, a model assigns values to variables and interpretations to the function and predicate symbols
- For some theories the problem is decidable (e.g., equality, linear arithmetic, arrays, …)

SMT in a nutshell

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- SMT framework = FOL + Theories
- Theory = Language + Class of Interpretations
- Examples:
  - Equality
  - Linear Arithmetic
  - Records
  - Lists
  - Combinations
  - …

SMT in a nutshell (cont'd)

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- Theories can be used to model many data types used in Computer Science
- SMT solving subsumes SAT solving but…
- … in practice, heuristics significantly improve on worst-case complexity…
- SMT-Lib initiative
- SMT solvers can be easily integrated in other tools

SMT solvers eat NP for lunch!
Byron Cook

SMT: why is it useful

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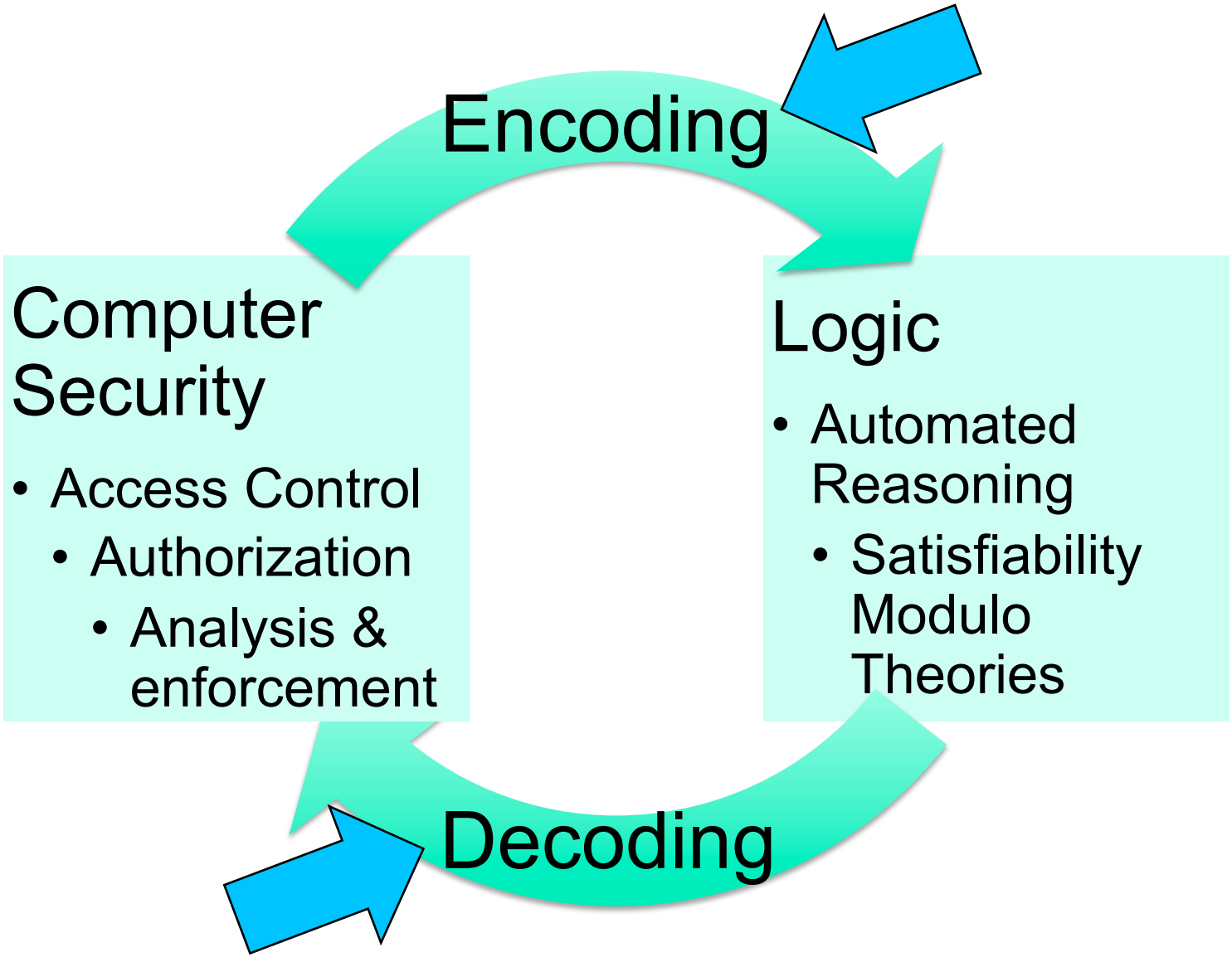
- Many combinatorial problems can be translated to satisfiability problems in (fragments of) FOL and …
- … available SMT solvers can efficiently solve such problems*!*

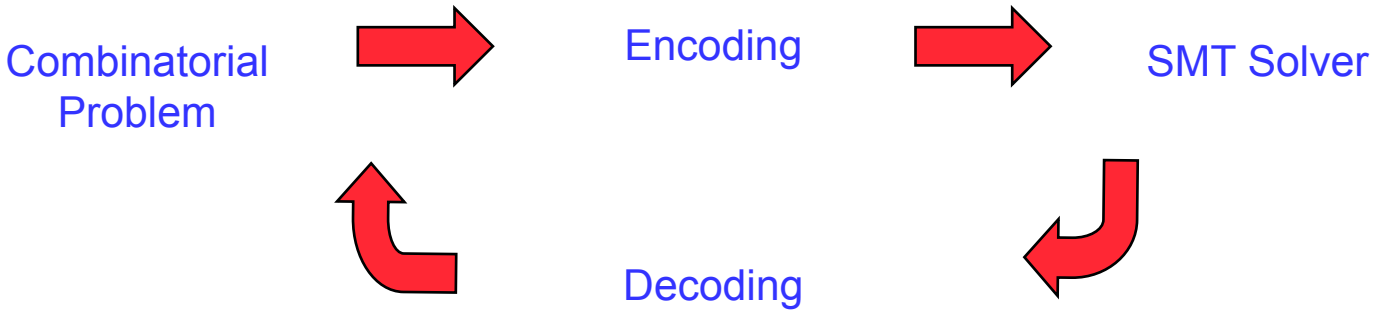
- For instance, SMT solving has been adopted in industrial verification
  - Z3 @ Microsoft
  - MathSat @ Intel, UTC
  - Yices @ Galois
  - others @ GrammaTech, NVIDIA, Dassault Aviation, …

Plan of the talk



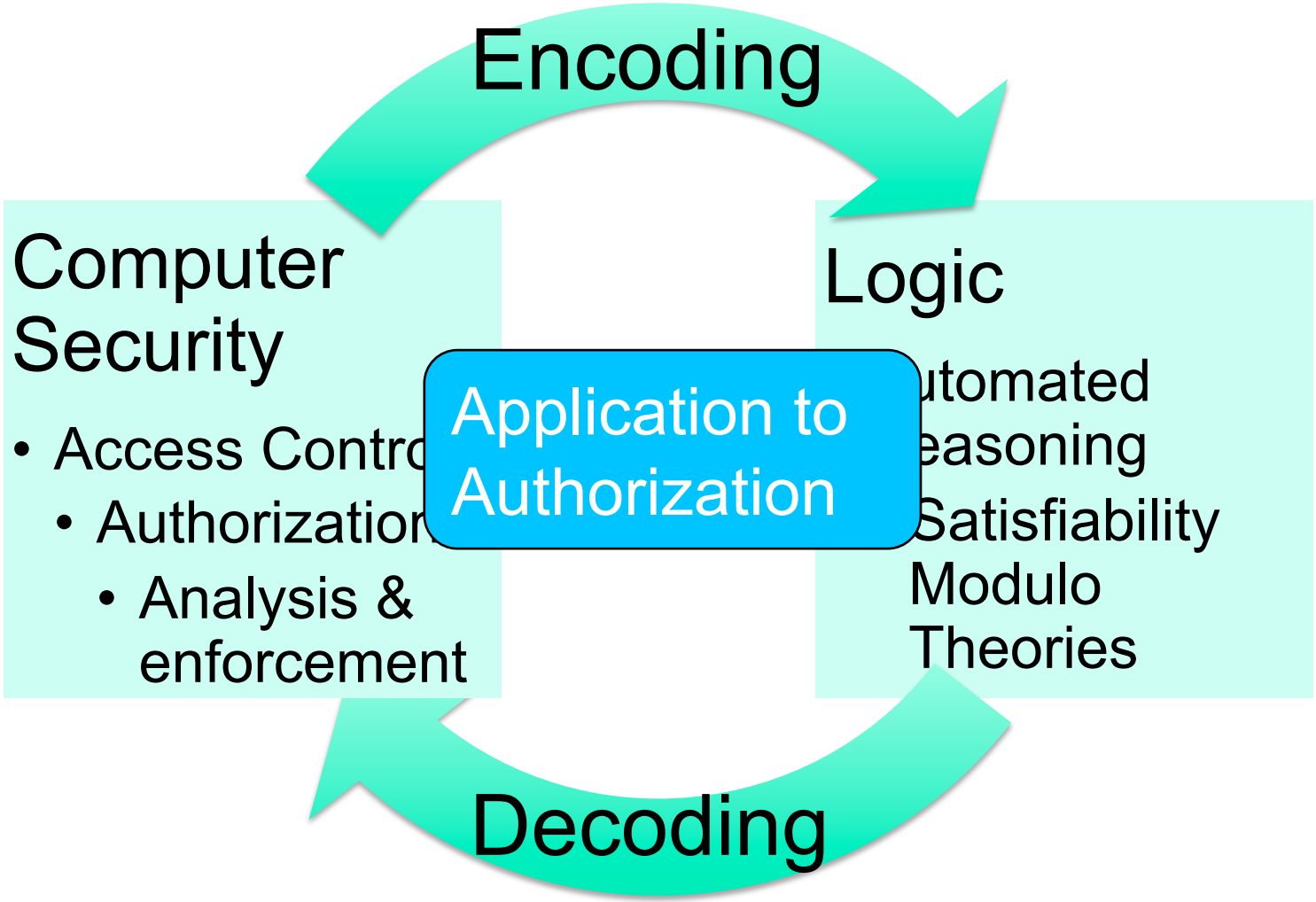
SMT: why is it useful (cont'd)

- Instead of developing specialized tools for solving combinatorial problems, …

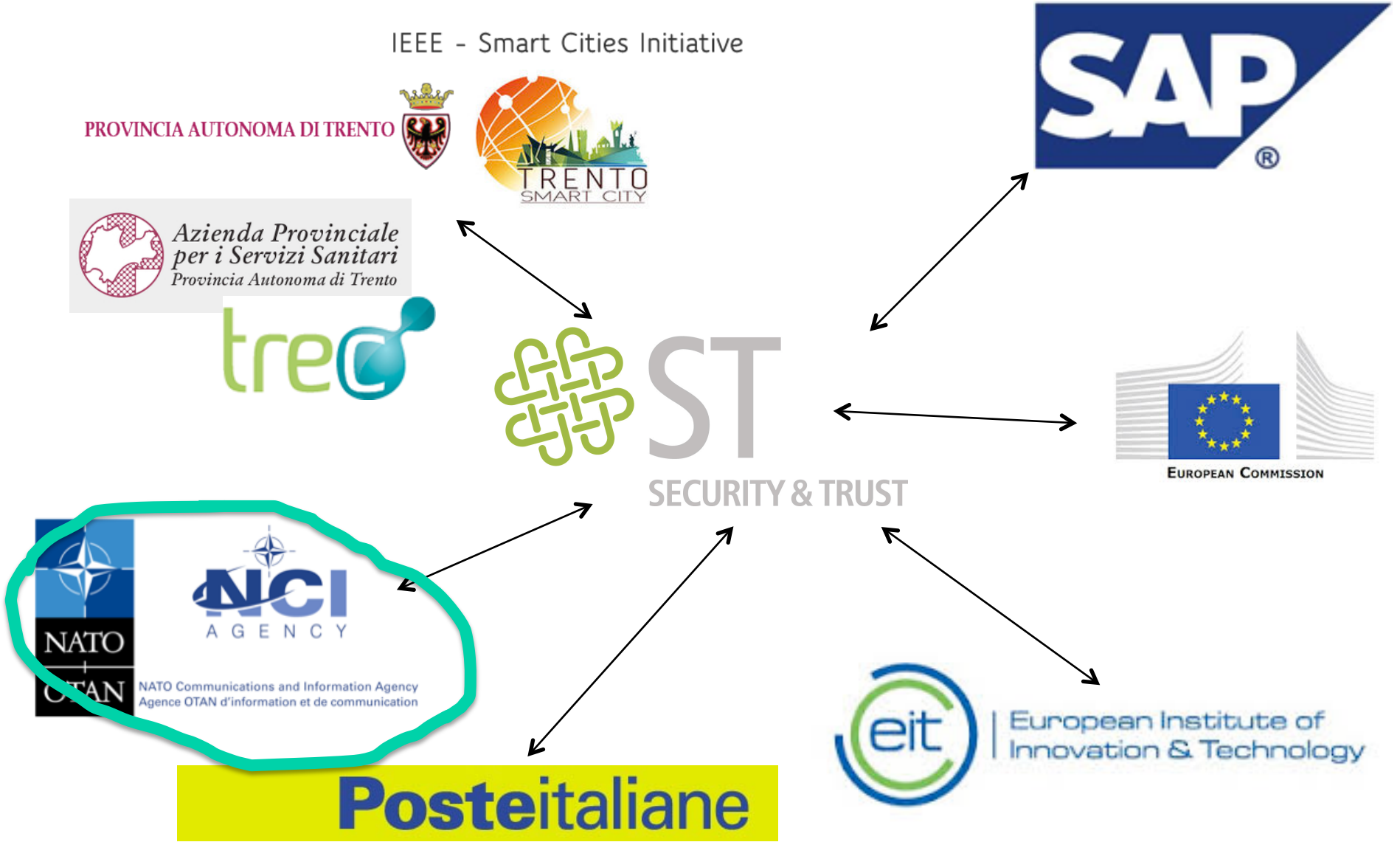


- Reuse of available knowledge about "Encoding" and "Decoding"

Plan of the talk



Our project with NATO-NCIA (2012-2015)



Context

- NATO network enabled capability and future mission network
  - High Assurance Automated Guard (HAAG)
- Selective information sharing for NATO operations
  - not only NATO members but also other governmental / humanitarian organizations
  - crucial for civil-military interaction, cyber defense information infrastructure, logistics support in the theatre
  - maximize effectiveness of operations and minimize disclosure with negative impact
- Variety of resources: Word documents, KML (Google) maps, XML documents, …
- Creators of documents have different psychological profiles leading to over/under classification

CPR (Content-based Protection and Release)

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Content-based

- structured resources = data containers
- atomic data associated to descriptive pairs of the form (element, content-metadata)
- For the moment, we assume that descriptive pairs exist… we ignore how they are extracted from resources… so that access control can be agnostic of the type of resources

Thus CPR can be seen as a refinement of ABAC and can be useful to large enterprises/organizations besides NATO

CPR (cont'd)

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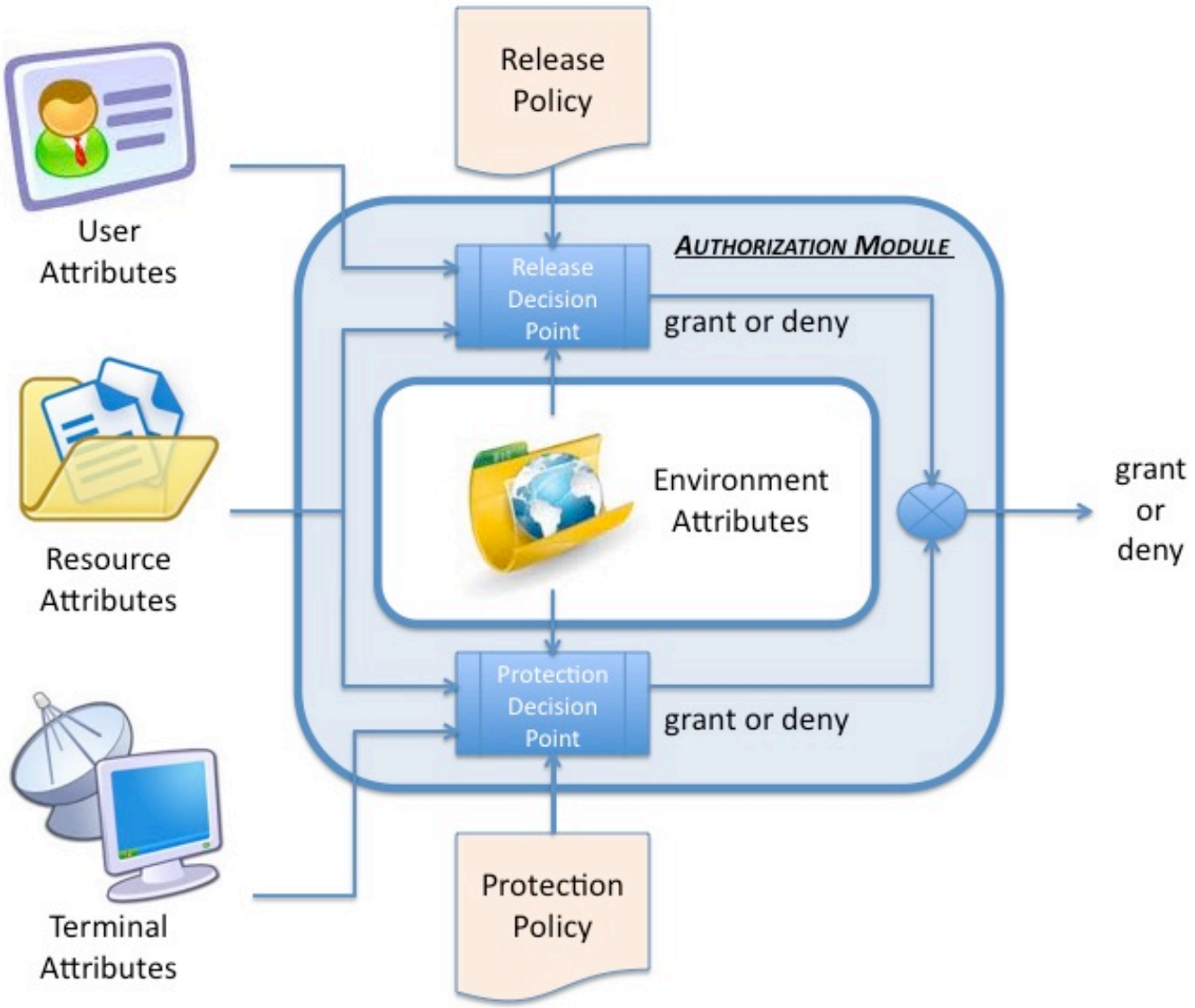
Protection and **R**elease

- seeking the best trade-off between
  - disclosing selected parts of resources to trusted users (release)
  - ensuring use of "secure enough" terminals, i.e. device + communication channels + local data handling capabilities (protection)
- allowing for separate administration of release and protection policies
  - release policy admins = experts in matching user clearance with sensitivity of data
  - protection policy admins = experts in HW/SW requirements specified in technical directives and security settings documents

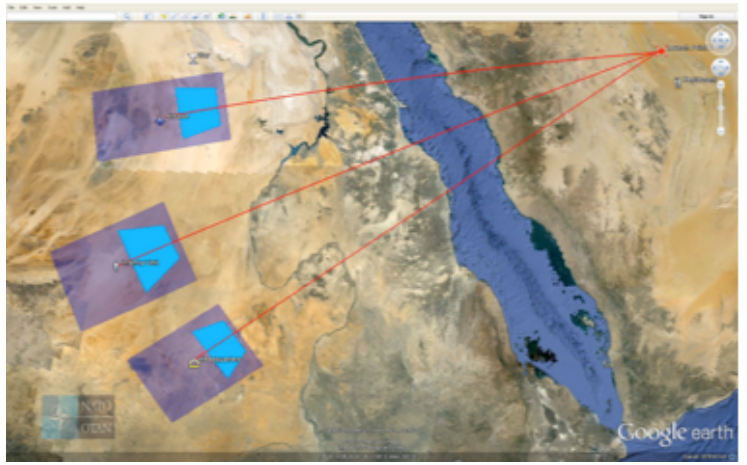
The core CPR Access Control model



An example: logistics support in the theatre

Passive Missile Defense System (PMD)

- simulates intercepting missile and consequences
- generates richly annotated KML maps



Access conditions

- NATO employees with clearance Secret can access resources whose content-metadata label category is Description… [release]
- Terminals managed by any authority with no information about their configuration can handle resources whose content-metadata label category is Public Information [protection]

Result of access control is **more than grant/deny**:

it is a **view of the document** according to policies

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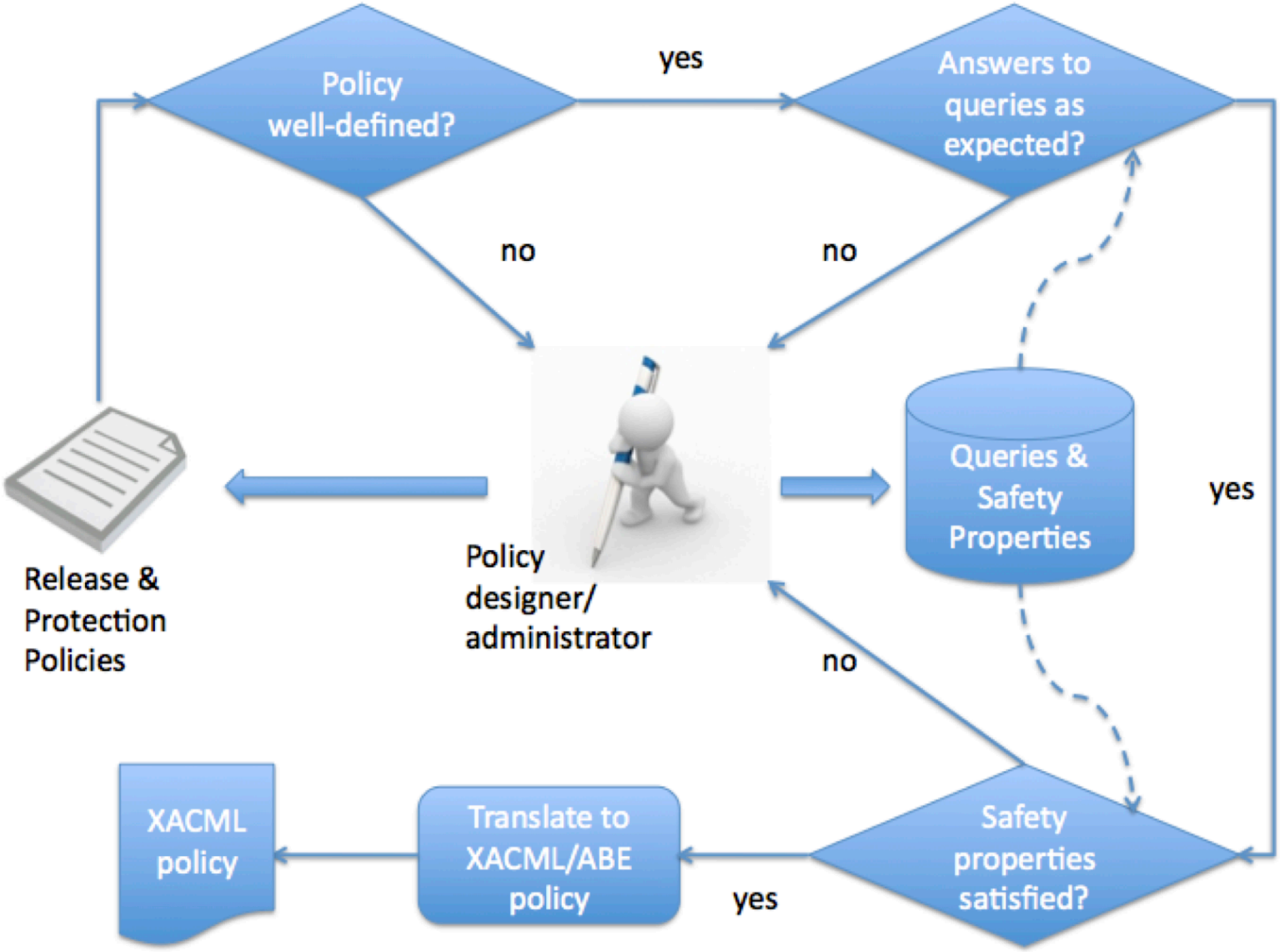
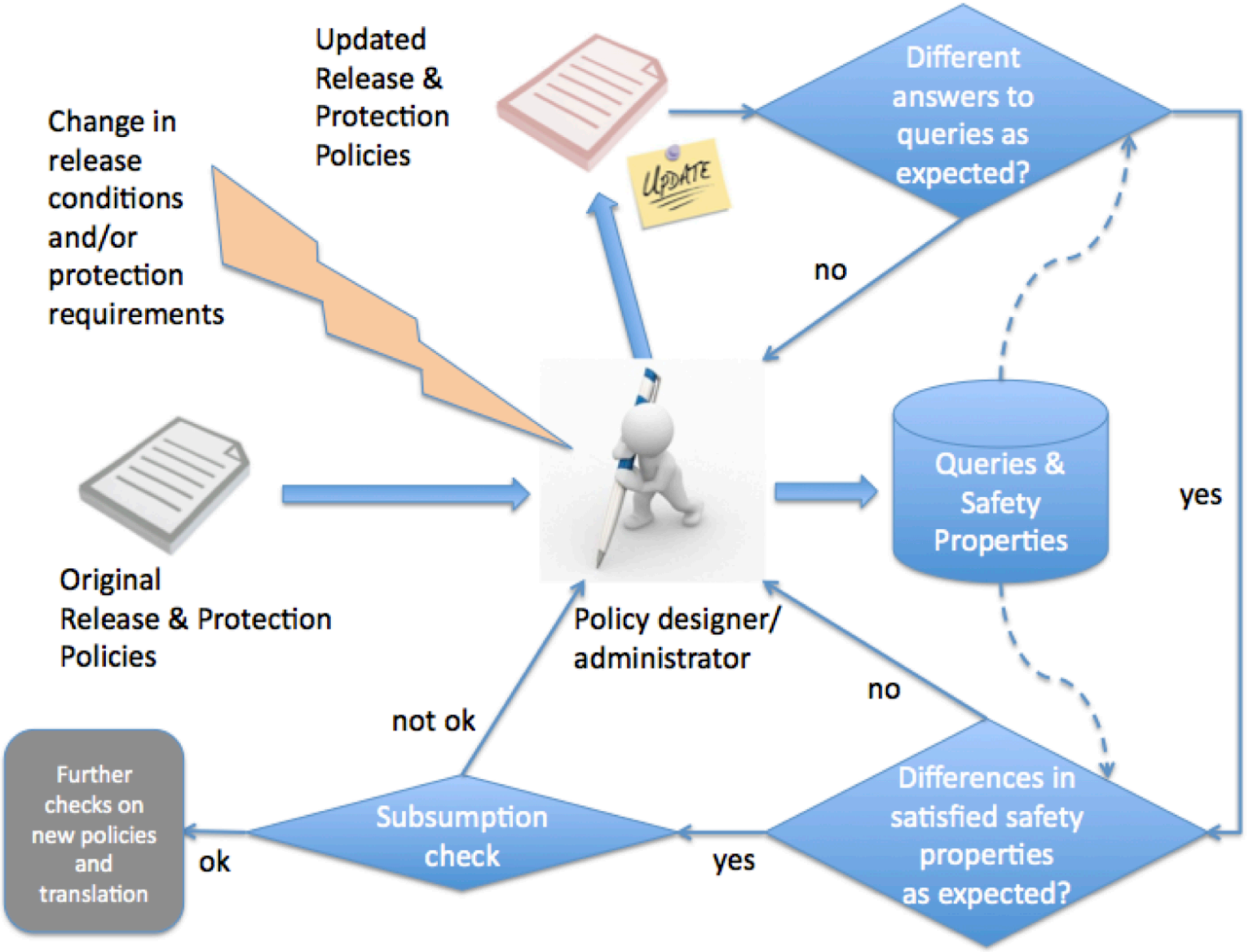
Demo with CPR Tool

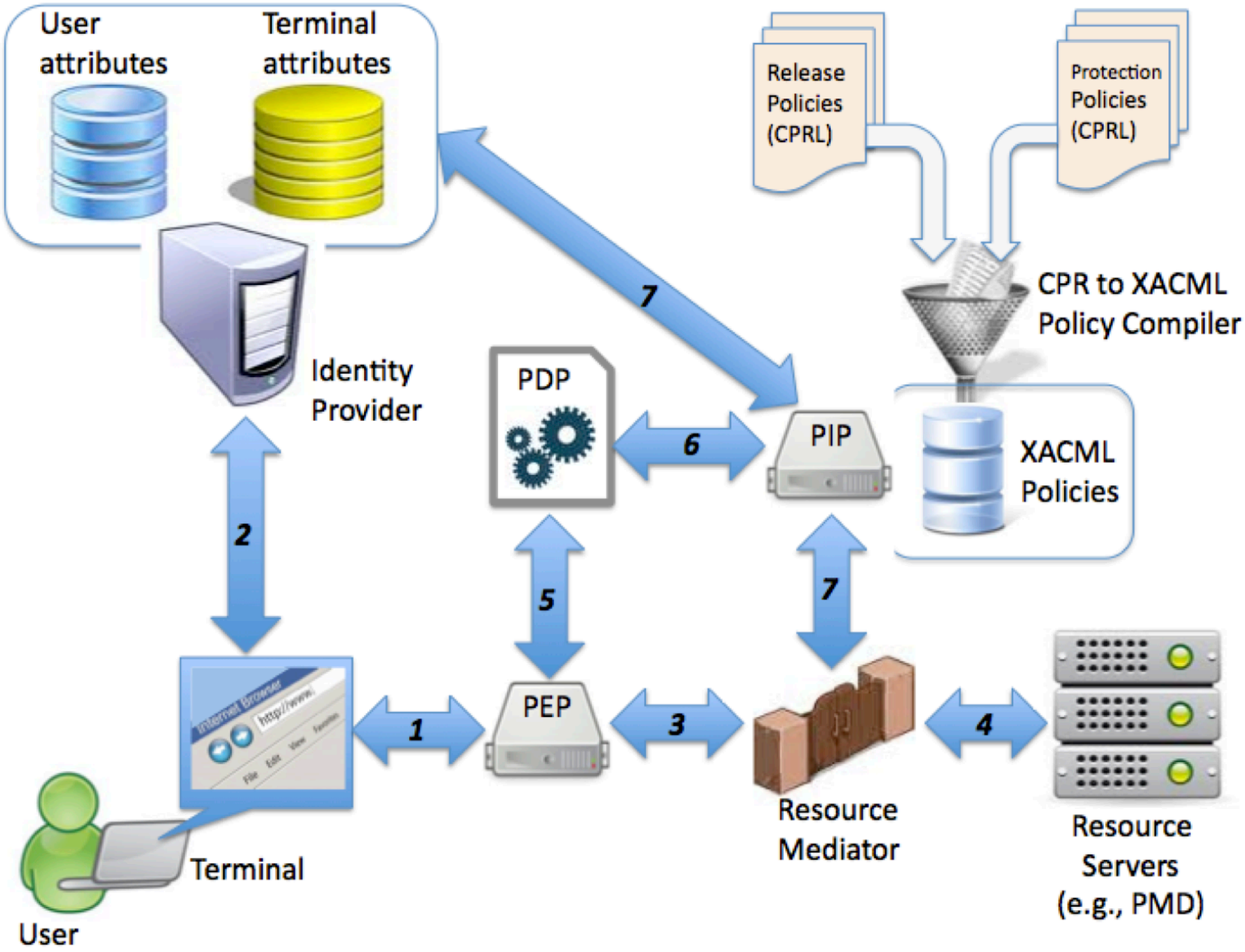
CPR Tool in the policy development lifecycle (I)



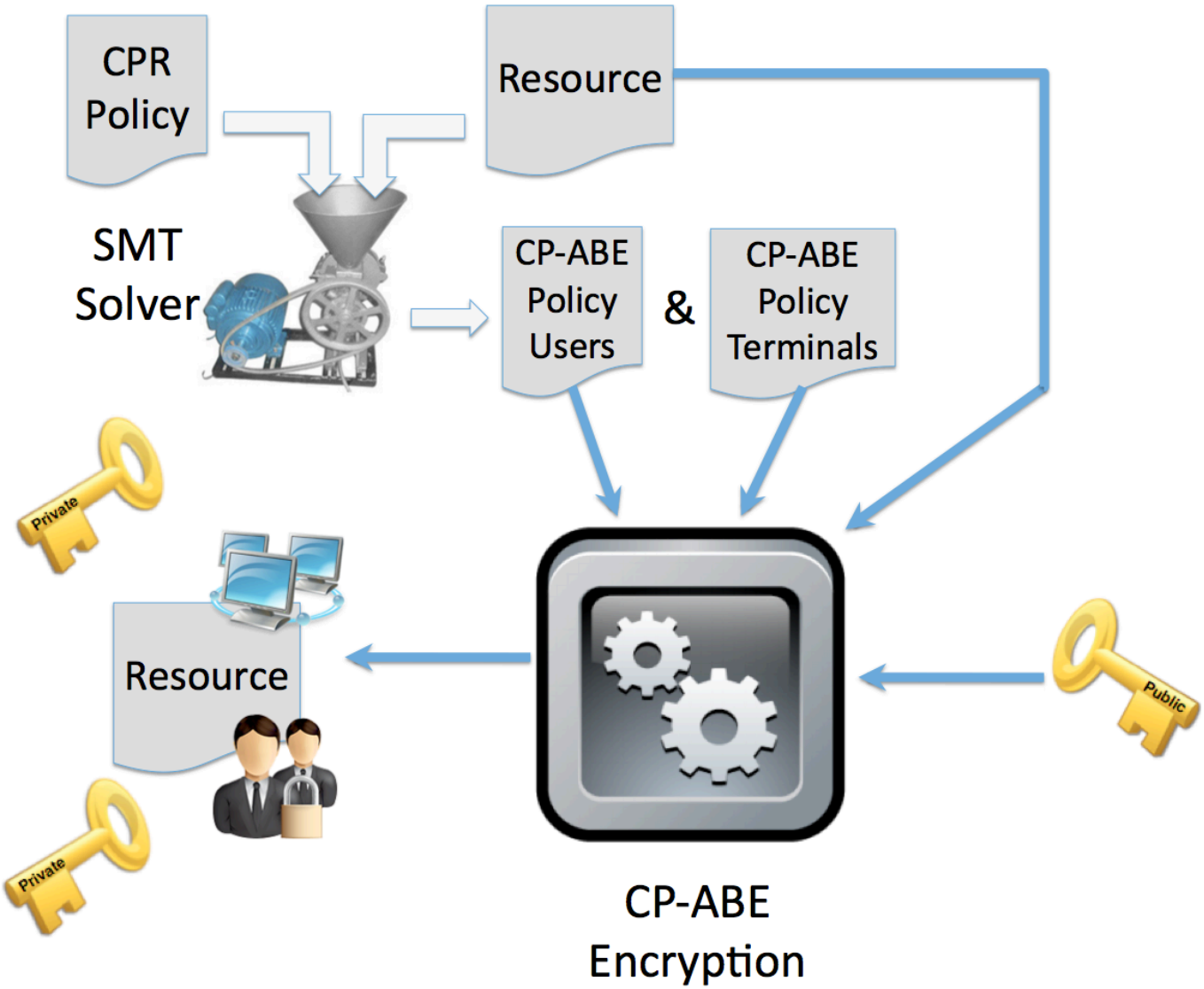
CPR Tool in the policy development lifecycle (II)



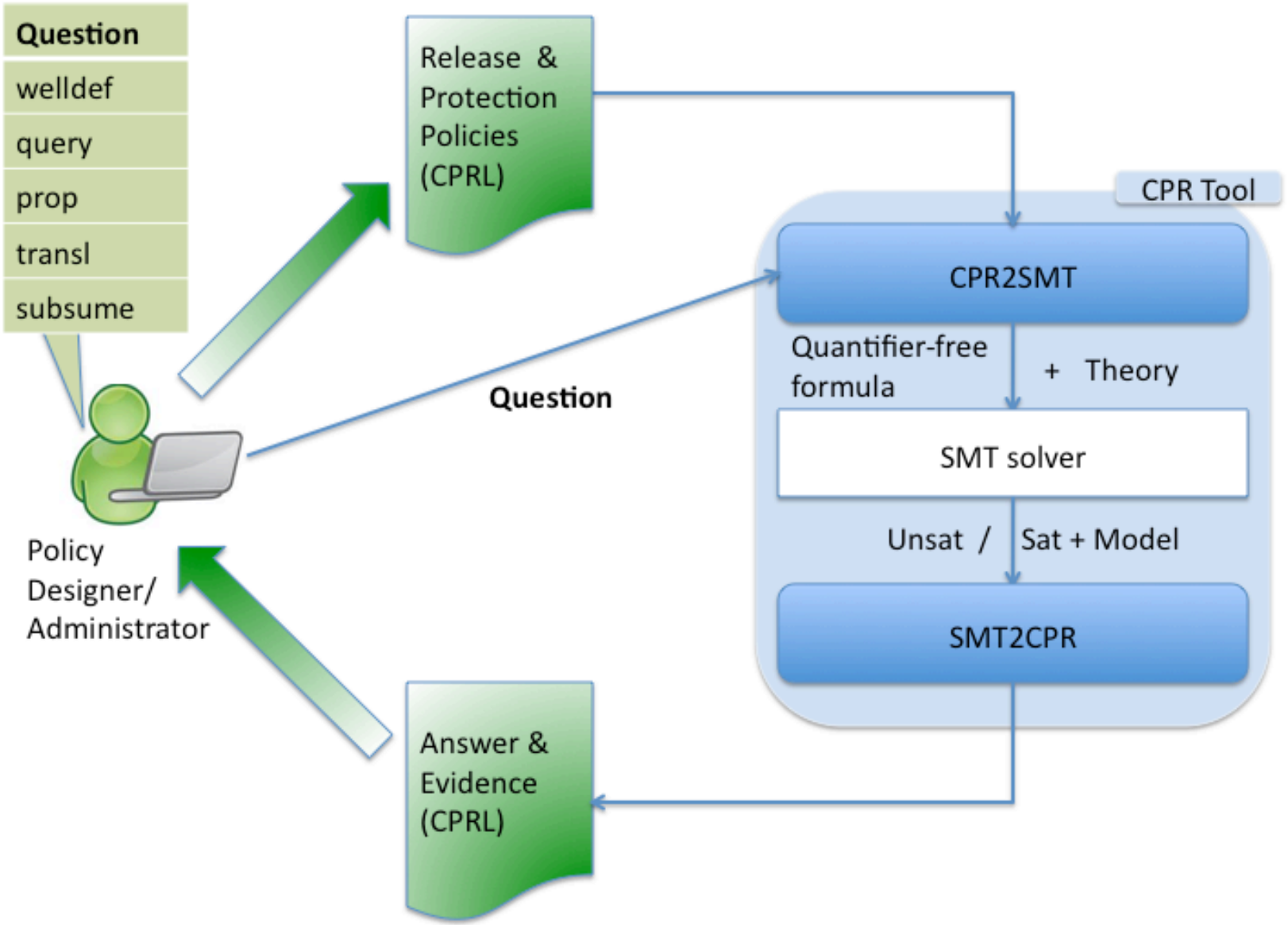
CPR Tool: Enforcement (XACML)



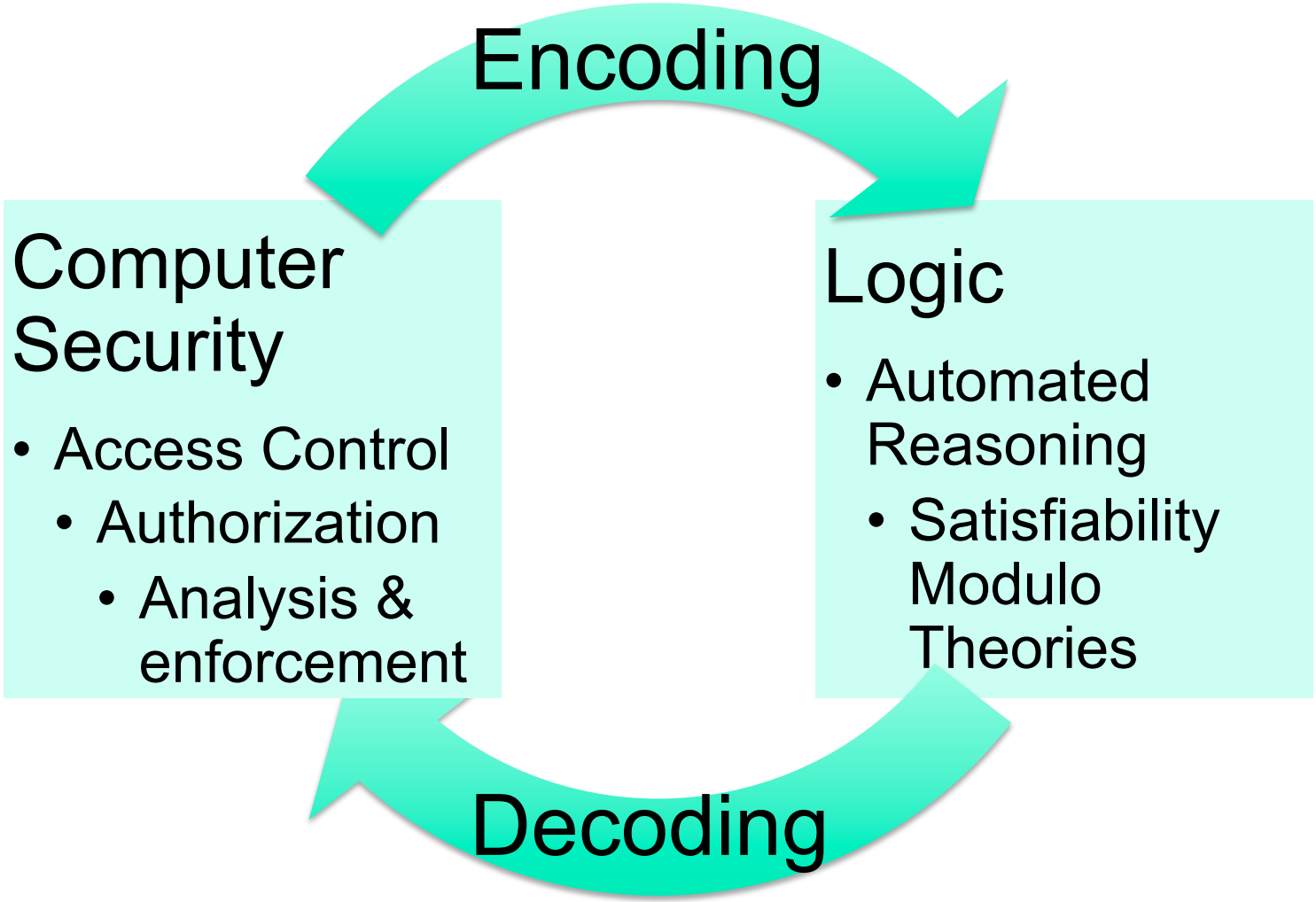
CPR Tool: Enforcement (Cloud)



CPR Tool: Architecture



Summary of the talk



Key takeways: CS side

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① Separate design and implementation

- Design pbs are already difficult to handle and a great source of vulnerabilities [recurring phenomenon in CS]
- Minimize implementation pbs by designing compilation to various enforcement mechanisms for different technological scenarios

② Use push-button tools for design, maintenance, and enforcement

- No need to know details of analysis techniques
- Support for wide range of analyses to support entire life-cycle

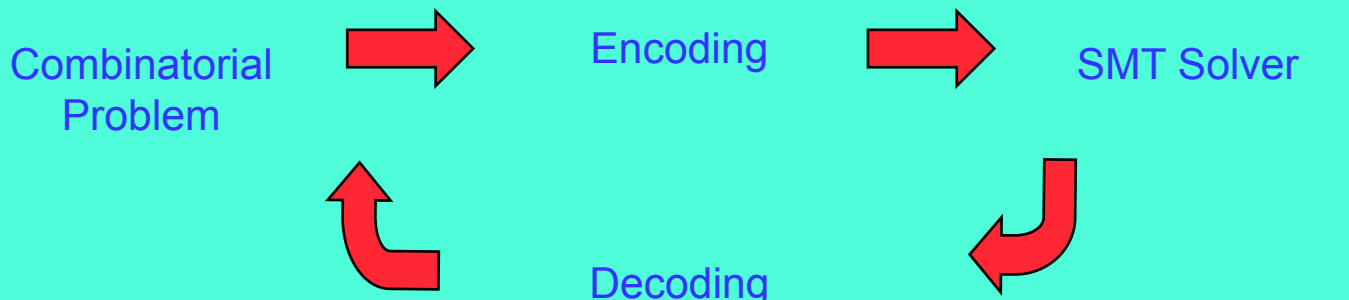
Key takeways: SMT side

Be lazy when developing analysis tools!

Don't build a new tool, try to use someone else!

Adapted from L. C. Paulson

Here is the recipe to do this:



Adapted from H. Kautz

Want to join?

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Drop me an email!

ranise@fbk.eu

ST
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Bibliography (about NATO project)

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