Formal Methods and Cryptography

Lecture 24
Formal Methods
Formal Methods

Logical foundations of computer science
Formal Methods

- Logical foundations of computer science
- A language that “machines can understand”
Formal Methods

- Logical foundations of computer science
- A language that "machines can understand"
- To specify a computational procedure fully formally
Formal Methods

- Logical foundations of computer science
  - A language that “machines can understand”
  - To specify a computational procedure fully formally
  - Don’t always need a computer: language abstracts away details not relevant to properties sought
Formal Methods

- Logical foundations of computer science
  - A language that “machines can understand”
  - To specify a computational procedure fully formally
  - Don’t always need a computer: language abstracts away details not relevant to properties sought
- Widely applied in practice
Formal Methods

- Logical foundations of computer science
- A language that “machines can understand”
- To specify a computational procedure fully formally
- Don’t always need a computer: language abstracts away details not relevant to properties sought
- Widely applied in practice
  - Ensures that the procedures designed/analyzed and those implemented are the same
Formal Methods

- Logical foundations of computer science
- A language that “machines can understand”
- To specify a computational procedure fully formally
- Don’t always need a computer: language abstracts away details not relevant to properties sought

- Widely applied in practice

- Ensures that the procedures designed/analyzed and those implemented are the same
- Can automate analysis of the designed procedures
Formal Methods in Cryptography
Formal Methods in Cryptography

Motivation: security bugs even in simple protocols, if system is under-specified; exhaustive analysis by hand is error-prone
Formal Methods in Cryptography

Motivation: security bugs even in simple protocols, if system is under-specified; exhaustive analysis by hand is error-prone

A language to unambiguously specify cryptographic protocols and the whole system (in terms of basic building blocks)
Formal Methods in Cryptography

- Motivation: security bugs even in simple protocols, if system is under-specified; exhaustive analysis by hand is error-prone
- A language to unambiguously specify cryptographic protocols and the whole system (in terms of basic building blocks)
- Automated analysis
Formal Methods in Cryptography

Motivation: security bugs even in simple protocols, if system is under-specified; exhaustive analysis by hand is error-prone

A language to unambiguously specify cryptographic protocols and the whole system (in terms of basic building blocks)

Automated analysis

Security definitions for various tasks are (were) often a list of intuitive high-level properties that must hold in adversarial environments
Formal Methods in Cryptography

- Motivation: security bugs even in simple protocols, if system is under-specified; exhaustive analysis by hand is error-prone
- A language to unambiguously specify cryptographic protocols and the whole system (in terms of basic building blocks)
- Automated analysis
  - Security definitions for various tasks are (were) often a list of intuitive high-level properties that must hold in adversarial environments
  - Formal methods Goal: to be able to analyze any given protocol and see if it satisfies these properties
Formal Methods in Cryptography

- Motivation: security bugs even in simple protocols, if system is under-specified; exhaustive analysis by hand is error-prone.
- A language to unambiguously specify cryptographic protocols and the whole system (in terms of basic building blocks).
- Automated analysis
  - Security definitions for various tasks are (were) often a list of intuitive high-level properties that must hold in adversarial environments.
  - Formal methods goal: to be able to analyze any given protocol and see if it satisfies these properties.
    - As opposed to finding one protocol (by hand) that satisfies the properties.
Formal Methods in Cryptography
Formal Methods in Cryptography

Outline:
Formal Methods in Cryptography

Outline:

- Develop a formal language for modeling the entire system (protocol, adversary, environment) and its evolution
Formal Methods in Cryptography

Outline:

- Develop a formal language for modeling the entire system (protocol, adversary, environment) and its evolution
- Use abstractions of cryptographic primitives like encryption
Formal Methods in Cryptography

Outline:

- Develop a formal language for modeling the entire system (protocol, adversary, environment) and its evolution
- Use abstractions of cryptographic primitives like encryption
- Define security properties in this language
Formal Methods in Cryptography

Outline:

- Develop a formal language for modeling the entire system (protocol, adversary, environment) and its evolution
- Use abstractions of cryptographic primitives like encryption
- Define security properties in this language
- Given any concrete protocol, map it to the formal language, and use standard formal method tools to automatically analyze it for the security properties
Formal Methods in Cryptography

Outline:

- Develop a formal language for modeling the entire system (protocol, adversary, environment) and its evolution
- Use abstractions of cryptographic primitives like encryption
- Define security properties in this language
- Given any concrete protocol, map it to the formal language, and use standard formal method tools to automatically analyze it for the security properties
- Ensure that security/insecurity in the formal model has useful implications in a more realistic model
Modeling
Modeling

- Typically, adversary controls the network
Modeling

- Typically, adversary controls the network
- A “process algebra” or a logic framework to describe what can happen in the system
Modeling

- Typically, adversary controls the network
- A “process algebra” or a logic framework to describe what can happen in the system
  - Dolev-Yao algebra: Parties can use keys to “encrypt” messages to get opaque symbols that can be operated on only if key is also provided. Deterministic encryption.
Modeling

- Typically, adversary controls the network
- A “process algebra” or a logic framework to describe what can happen in the system
  - Dolev-Yao algebra: Parties can use keys to “encrypt” messages to get opaque symbols that can be operated on only if key is also provided. Deterministic encryption.
  - BAN logic [Burrows-Abadi-Needham]: principals (parties) can “say” or “see” messages, and “believe” statements like “A said M” or “A believes B said M”. Includes a notion of shared keys and public/private keys used for “encryption” (or rather, signcryption)
Modeling

- Typically, adversary controls the network
- A “process algebra” or a logic framework to describe what can happen in the system
  - Dolev-Yao algebra: Parties can use keys to “encrypt” messages to get opaque symbols that can be operated on only if key is also provided. Deterministic encryption.
  - BAN logic [Burrows-Abadi-Needham]: principals (parties) can “say” or “see” messages, and “believe” statements like “A said M” or “A believes B said M”. Includes a notion of shared keys and public/private keys used for “encryption” (or rather, signcryption)
  - spi calculus: incorporates an “encryption” primitive to pi calculus which is used to model concurrent, communicating systems
Modeling
Modeling

- e.g. Dolev-Yao
Modeling

- e.g. Dolev-Yao

- Term-rewriting algebra: operations that can lead to new events are defined by rules for writing new terms
Modeling

- e.g. Dolev-Yao

Term-rewriting algebra: operations that can lead to new events are defined by rules for writing new terms

Operations: send/receive terms; pick “nonces”; pair/separate; “encrypt”/“decrypt”
Modeling

- e.g. Dolev-Yao

Term-rewriting algebra: operations that can lead to new events are defined by rules for writing new terms

Operations: send/receive terms; pick “nonces”; pair/separate; “encrypt”/“decrypt”

- For each user $X$, public operation $E_X$ and private operation $D_X$
Modeling

e.g. Dolev-Yao

Term-rewriting algebra: operations that can lead to new events are defined by rules for writing new terms

Operations: send/receive terms; pick “nonces”; pair/separate; “encrypt”/“decrypt”

For each user $X$, public operation $E_X$ and private operation $D_X$

$D_X(E_X(m))$ can be rewritten as $m$
Modeling

e.g. Dolev-Yao

Term-rewriting algebra: operations that can lead to new events are defined by rules for writing new terms

Operations: send/receive terms; pick “nonces”; pair/separate; “encrypt”/“decrypt”

For each user X, public operation $E_X$ and private operation $D_X$

$D_X(E_X(m))$ can be rewritten as $m$

Separate(Pair(a,b)) gives a,b
Modeling

e.g. Dolev-Yao

Term-rewriting algebra: operations that can lead to new events are defined by rules for writing new terms

Operations: send/receive terms; pick “nonces”; pair/separate; “encrypt”/“decrypt”

For each user $X$, public operation $E_X$ and private operation $D_X$

$D_X(E_X(m))$ can be rewritten as $m$

Separate(Pair(a,b)) gives a,b

No other rewritings; each party can use terms it received and rewrite them (according to the protocol); adversary can obtain the closure of all terms sent out in the network
Security Properties
Security Properties

- Valid trace of a system: a sequence of events possible in the system (for the given protocol and an arbitrary adversary)
Security Properties

- Valid trace of a system: a sequence of events possible in the system (for the given protocol and an arbitrary adversary)
- Event: input/output/communication by parties or adversary
Security Properties

- Valid trace of a system: a sequence of events possible in the system (for the given protocol and an arbitrary adversary)
  - Event: input/output/communication by parties or adversary
- Security property is defined for a trace, and a protocol is called secure if all valid traces satisfy the security property
Security Properties

- Valid trace of a system: a sequence of events possible in the system (for the given protocol and an arbitrary adversary)
  - Event: input/output/communication by parties or adversary
  - Security property is defined for a trace, and a protocol is called secure if all valid traces satisfy the security property
  - e.g.: For a key-agreement protocol, a trace is insecure if it has Alice outputting a nonce R (i.e., event [Alice:(output,R)] ) and the adversary also outputting R (event [Eve:(output,R)] )
Security Properties

- Valid trace of a system: a sequence of events possible in the system (for the given protocol and an arbitrary adversary)

- Event: input/output/communication by parties or adversary

- Security property is defined for a trace, and a protocol is called secure if all valid traces satisfy the security property

  e.g.: For a key-agreement protocol, a trace is insecure if it has Alice outputting a nonce R (i.e., event [Alice:(output,R)] ) and the adversary also outputting R (event [Eve:(output,R)] )

  e.g.: (in BAN logic) “(A believes B said X) at some point ⇒ (B said X) before that point”
Security Properties
Security Properties

- Security in spi calculus (inherited from pi calculus) essentially same as simulation-based security
Security Properties

- Security in spi calculus (inherited from pi calculus) essentially the same as simulation-based security

- Observational Equivalence: Two systems P, Q are observationally equivalent if for all systems (environments) Z, the systems (Z|P) and (Z|Q) produce the same outputs
Security Properties

Security in spi calculus (inherited from pi calculus) essentially same as simulation-based security

Observational Equivalence: Two systems P, Q are observationally equivalent if for all systems (environments) Z, the systems (Z|P) and (Z|Q) produce the same outputs

To define security of a protocol, define an ideal protocol (think as ideal functionality, combined with a simulator for the “dummy adversary”) and require that the two systems are observationally equivalent
Security Properties

Security in spi calculus (inherited from pi calculus) essentially same as simulation-based security

Observational Equivalence: Two systems P, Q are observationally equivalent if for all systems (environments) Z, the systems (Z|P) and (Z|Q) produce the same outputs

To define security of a protocol, define an ideal protocol (think as ideal functionality, combined with a simulator for the "dummy adversary") and require that the two systems are observationally equivalent

(But spi calculus incorporates an ideal shared-key encryption and no other cryptographic features; typically limited to secure communication tasks)
An Example
An Example

- Needham-Schroeder-Lowe (public-key) protocol
An Example

- Needham-Schroeder-Lowe (public-key) protocol
- For “mutual authentication”
An Example

- Needham-Schroeder-Lowe (public-key) protocol
- For "mutual authentication"
- Or, for "key agreement"
An Example

- Needham-Schroeder-Lowe (public-key) protocol

  - For “mutual authentication”
  - Or, for “key agreement”

- Uses an ideal encryption (or signcryption) to let two parties exchange nonces so that each should know that the nonce came from the other party (whose public-key it already has)
An Example

- Needham-Schroeder-Lowe (public-key) protocol
  - For “mutual authentication”
  - Or, for “key agreement”

- Uses an ideal encryption (or signcryption) to let two parties exchange nonces so that each should know that the nonce came from the other party (whose public-key it already has)

- The nonce should be useful as a secret shared-key
An Example

- Needham-Schroeder-Lowe (public-key) protocol
  - For “mutual authentication”
  - Or, for “key agreement”

- Uses an ideal encryption (or signcryption) to let two parties exchange nonces so that each should know that the nonce came from the other party (whose public-key it already has)
  - The nonce should be useful as a secret shared-key

- Most formal frameworks use this an example, to show that they can find the bug in the original Needham-Schroeder protocol (1978)
An Example

- Needham-Schroeder-Lowe (public-key) protocol

- For “mutual authentication”

- Or, for “key agreement”

- Uses an ideal encryption (or signcryption) to let two parties exchange nonces so that each should know that the nonce came from the other party (whose public-key it already has)

- The nonce should be useful as a secret shared-key

- Most formal frameworks use this an example, to show that they can find the bug in the original Needham-Schroeder protocol (1978)

- Or new bugs in extended settings
At this point, producing executions that do not correspond to an execution of a Dolev-Yao adversary. Our proposal states that the computational adversary (in the UC setting) has only a negligible chance of inducing an adversary to produce an execution where the outputs differ significantly from the intended outputs.

This section presents the Mapping Lemma, sketched in Section 2.3. Recall that this lemma is a crucial technical lemma.

Version 1:  $x=\text{na}$  (Initiator’s nonce output as secret key)
Version 2:  $x=\text{nb}$  (Responder’s nonce output as secret key)
Automated Analysis
Automated Analysis

- Not necessarily very efficient
Automated Analysis

- Not necessarily very efficient

- Often NP-hard (or even P-SPACE hard). Typical algorithms are exponential in the size of the system
Automated Analysis

- Not necessarily very efficient

- Often NP-hard (or even P-SPACE hard). Typical algorithms are exponential in the size of the system

- Typically undecidable when allowing an unbounded number of concurrent sessions
Automated Analysis

- Not necessarily very efficient
- Often NP-hard (or even P-SPACE hard). Typical algorithms are exponential in the size of the system
- Typically undecidable when allowing an unbounded number of concurrent sessions
- Popular models (Dolev-Yao, BAN logic, spi calculus) have reasonably efficient algorithms for analyzing a variety of security properties, if the system is small (single session)
Automated Analysis

- Not necessarily very efficient
- Often NP-hard (or even P-SPACE hard). Typical algorithms are exponential in the size of the system
- Typically undecidable when allowing an unbounded number of concurrent sessions
- Popular models (Dolev-Yao, BAN logic, spi calculus) have reasonably efficient algorithms for analyzing a variety of security properties, if the system is small (single session)
- Sometimes state-exploration (using model-checking tools) can be used to discover (some) flaws, but does not prove security
What does Security in a Formal Model mean?
What does Security in a Formal Model mean?

“Encryption” as proposed in most of the formal models attributes message secrecy, key-anonymity, non-malleability, circular-encryption security, MAC/signature properties and much more (while requiring it to be deterministic)
What does Security in a Formal Model mean?

“Encryption” as proposed in most of the formal models attributes message secrecy, key-anonymity, non-malleability, circular-encryption security, MAC/signature properties and much more (while requiring it to be deterministic)

Possibly achievable in random-oracle model or generic-group model
What does Security in a Formal Model mean?

- “Encryption” as proposed in most of the formal models attributes message secrecy, key-anonymity, non-malleability, circular-encryption security, MAC/signature properties and much more (while requiring it to be deterministic)
  - Possibly achievable in random-oracle model or generic-group model
- Security guarantee similar in spirit to these heuristic models
What does Security in a Formal Model mean?

- “Encryption” as proposed in most of the formal models attributes message secrecy, key-anonymity, non-malleability, circular-encryption security, MAC/signature properties and much more (while requiring it to be deterministic)

  - Possibly achievable in random-oracle model or generic-group model

- Security guarantee similar in spirit to these heuristic models

  - Security against adversaries who use only operations permitted by the formal model
What does Security in a Formal Model mean?
What does Security in a Formal Model mean?

Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
What does Security in a Formal Model mean?

- Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
- Not quite, but maybe strong enough to translate the formal-model guarantees to security guarantees in the computational model.
What does Security in a Formal Model mean?

- Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
- Not quite, but maybe strong enough to translate the formal-model guarantees to security guarantees in the computational model.
- A formal model is “sound” if we can do the following:
What does Security in a Formal Model mean?

- Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
  - Not quite, but maybe strong enough to translate the formal-model guarantees to security guarantees in the computational model.

A formal model is “sound” if we can do the following:

- Translate protocol in computational model to formal model. Get security guarantee for it in formal model. This should imply security of the original protocol in the computational model.
What does Security in a Formal Model mean?

- Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
- Not quite, but maybe strong enough to translate the formal-model guarantees to security guarantees in the computational model.

A formal model is “sound” if we can do the following:

- Translate protocol in computational model to formal model. Get security guarantee for it in formal model.
  This should imply security of the original protocol in the computational model.
What does Security in a Formal Model mean?

- Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
  - Not quite, but maybe strong enough to translate the formal-model guarantees to security guarantees in the computational model.

A formal model is “sound” if we can do the following:

- Translate protocol in computational model to formal model. Get security guarantee for it in formal model. This should imply security of the original protocol in the computational model.

In a specific format, using only specific primitives

If primitives satisfy certain security definitions
What does Security in a Formal Model mean?

- Can we develop strong underlying crypto primitives to implement the “encryption” as used in these formal models?
- Not quite, but maybe strong enough to translate the formal-model guarantees to security guarantees in the computational model.

A formal model is “sound” if we can do the following:

- Translate protocol in computational model to formal model. Get security guarantee for it in formal model. This should imply security of the original protocol in the computational model.
- Soundness of the formal model and formal security property for the computational task and primitive used.
Soundness of Formal Models
Soundness of Formal Models

Initiated by Abadi–Rogaway (2001)
Soundness of Formal Models

- Initiated by Abadi-Rogaway (2001)

- Shows soundness for a class of protocols/tasks, if CCA secure encryption is mapped to ideal encryptions in a formal model, and a certain security property is proven in the formal model.
Soundness of Formal Models

- Initiated by Abadi-Rogaway (2001)
- Shows soundness for a class of protocols/tasks, if CCA secure encryption is mapped to ideal encryptions in a formal model, and a certain security property is proven in the formal model.
- Since then extended to various authentication/key-agreement-like tasks (and some computation tasks), against passive and active adversaries, using different formal models (algebras, spi-calculus).
Soundness of Formal Models

- Initiated by Abadi-Rogaway (2001)

  Shows soundness for a class of protocols/tasks, if CCA secure encryption is mapped to ideal encryptions in a formal model, and a certain security property is proven in the formal model.

  Since then extended to various authentication/key-agreement-like tasks (and some computation tasks), against passive and active adversaries, using different formal models (algebras, spi-calculus).

  Recent works incorporate signatures, NIZK proofs etc.
Soundness of Formal Models

- Initiated by Abadi-Rogaway (2001)
- Shows soundness for a class of protocols/tasks, if CCA secure encryption is mapped to ideal encryptions in a formal model, and a certain security property is proven in the formal model.
- Since then extended to various authentication/key-agreement-like tasks (and some computation tasks), against passive and active adversaries, using different formal models (algebras, spi-calculus).
- Recent works incorporate signatures, NIZK proofs etc.
- Typically each work considers a specific task, develops a security criterion in a specific formal model, and establishes soundness for protocols using specific crypto primitives (like CCA2 encryption).
Soundness of Formal Models

Initiated by Abadi-Rogaway (2001)

- Shows soundness for a class of protocols/tasks, if CCA secure encryption is mapped to ideal encryptions in a formal model, and a certain security property is proven in the formal model.

- Since then extended to various authentication/key-agreement-like tasks (and some computation tasks), against passive and active adversaries, using different formal models (algebras, spi-calculus).

- Recent works incorporate signatures, NIZK proofs etc.

- Typically each work considers a specific task, develops a security criterion in a specific formal model, and establishes soundness for protocols using specific crypto primitives (like CCA2 encryption).

- A somewhat general framework by Backes et al. (CCS 2009)
Soundness of Formal Models
Soundness of Formal Models

- Several challenges
Soundness of Formal Models

- Several challenges

  - Traditional models usually deterministic (except for picking nonces, and possibly within the encryption operation), but for many interesting tasks cryptographic protocols typically use more randomness
Soundness of Formal Models

- Several challenges

- Traditional models usually deterministic (except for picking nonces, and possibly within the encryption operation), but for many interesting tasks cryptographic protocols typically use more randomness

- If model is too general, becomes hard/intractable to automatically reason
Soundness of Formal Models

Several challenges

Traditional models usually deterministic (except for picking nonces, and possibly within the encryption operation), but for many interesting tasks cryptographic protocols typically use more randomness.

If model is too general, becomes hard/intractable to automatically reason.

Promising approach: Universal Composition -- require stronger per-session security that will allow decomposing the analysis to be per-session.
Soundness of Formal Models

Several challenges

Traditional models usually deterministic (except for picking nonces, and possibly within the encryption operation), but for many interesting tasks cryptographic protocols typically use more randomness

If model is too general, becomes hard/intractable to automatically reason

Promising approach: Universal Composition -- require stronger per-session security that will allow decomposing the analysis to be per-session

Only a few security properties have been considered (related to authentication and secure communication). Need to identify automatically verifiable (and sufficient) criteria for each new task
Universal Composition
Universal Composition

- Recall: security guarantee (in computational model) in terms of an ideal functionality (can be used in a formal model)
Universal Composition

- Recall: security guarantee (in computational model) in terms of an ideal functionality (can be used in a formal model)

  - From [GMW’87]. Used by [Pfitzmann-Waidner’01] and [Canetti’01]
Universal Composition

- Recall: security guarantee (in computational model) in terms of an ideal functionality (can be used in a formal model)
  - From [GMW’87]. Used by [Pfitzmann-Waidner’01] and [Canetti’01]
- UC Security [Canetti’01]: security is defined for one session of the protocol, in the presence of an arbitrary environment
Universal Composition

Recall: security guarantee (in computational model) in terms of an ideal functionality (can be used in a formal model)

From [GMW'87]. Used by [Pfitzmann-Waidner’01] and [Canetti’01]

UC Security [Canetti’01]: security is defined for one session of the protocol, in the presence of an arbitrary environment

Composition Theorem: UC security of individual sessions automatically implies UC security of multiple concurrent sessions
Universal Composition

- Recall: security guarantee (in computational model) in terms of an ideal functionality (can be used in a formal model)
  - From [GMW’87]. Used by [Pfitzmann-Waidner’01] and [Canetti’01]
- UC Security [Canetti’01]: security is defined for one session of the protocol, in the presence of an arbitrary environment
- Composition Theorem: UC security of individual sessions automatically implies UC security of multiple concurrent sessions
- Drawback: a strong security requirement that is more “expensive” to realize
Universal Composition

- Recall: security guarantee (in computational model) in terms of an ideal functionality (can be used in a formal model)

  - From [GMW’87]. Used by [Pfitzmann-Waidner’01] and [Canetti’01]

- UC Security [Canetti’01]: security is defined for one session of the protocol, in the presence of an arbitrary environment

- Composition Theorem: UC security of individual sessions automatically implies UC security of multiple concurrent sessions

  - Drawback: a strong security requirement that is more “expensive” to realize

  - Advantages: 1. Security for concurrent sessions. 2. Easy to use as a sub-module in higher level protocols and analyze security. Analysis of higher level protocols often “automatable”
Composition Logic
Composition Logic

- On going research
Composition Logic

- On-going research
- Protocol Composition Logic of Mitchell et al.
Composition Logic

- On going research
- Protocol Composition Logic of Mitchell et al.
- Formal model and soundness theorems by Canetti-Herzog
Composition Logic

- On going research
- Protocol Composition Logic of Mitchell et al.
- Formal model and soundness theorems by Canetti-Herzog
- ...
Secure Computation?

- Most tasks formally analyzed still relate to secure communication
Secure Computation?

- Most tasks formally analyzed still relate to secure communication
- UC framework in principle allows arbitrary functionalities
Secure Computation?

- Most tasks formally analyzed still relate to secure communication
- UC framework in principle allows arbitrary functionalities
- Also, possibility of modeling certain homomorphic encryption schemes algebraically (and in a sound manner) if implemented using “non-malleable” homomorphic encryption
Secure Computation?

- Most tasks formally analyzed still relate to secure communication
- UC framework in principle allows arbitrary functionalities
- Also, possibility of modeling certain homomorphic encryption schemes algebraically (and in a sound manner) if implemented using “non-malleable” homomorphic encryption
- Challenge: Efficient automated analysis in the resulting formal model
More Automation?
More Automation?

Formal models are used to analyze higher level protocols, reducing their security to security of underlying cryptographic primitives.
More Automation?

- Formal models are used to analyze higher level protocols, reducing their security to security of underlying cryptographic primitives.
- Crypto primitives themselves designed and security reduced to computational complexity assumptions by hand.
More Automation?

- Formal models are used to analyze higher level protocols, reducing their security to security of underlying cryptographic primitives.
- Crypto primitives themselves designed and security reduced to computational complexity assumptions by hand.
- Can this be automated?
More Automation?

- Formal models are used to analyze higher level protocols, reducing their security to security of underlying cryptographic primitives.

- Crypto primitives themselves designed and security reduced to computational complexity assumptions by hand.

- Can this be automated?

  - Plausible, if a formal model of complexity assumptions.
More Automation?

- Formal models are used to analyze higher level protocols, reducing their security to security of underlying cryptographic primitives.
- Crypto primitives themselves designed and security reduced to computational complexity assumptions by hand.
- Can this be automated?
  - Plausible, if a formal model of complexity assumptions.
  - Likely, for generic group model (which is a formal model).
Today
Today

- Use of formal methods in cryptography
Today

- Use of formal methods in cryptography
- Prior to 2000 (or Abadi-Rogaway), separate communities
Today

- Use of formal methods in cryptography
  - Prior to 2000 (or Abadi-Rogaway), separate communities
  - Dolev-Yao, spi calculus, BAN logic
Today

- Use of formal methods in cryptography
- Prior to 2000 (or Abadi-Rogaway), separate communities
  - Dolev-Yao, spi calculus, BAN logic
  - Security in formal model had little bearing as a security guarantee in the computational model (but attacks in the formal model give real attacks)
Today

- Use of formal methods in cryptography
  - Prior to 2000 (or Abadi-Rogaway), separate communities
    - Dolev-Yao, spi calculus, BAN logic
  - Security in formal model had little bearing as a security guarantee in the computational model (but attacks in the formal model give real attacks)
- Soundness guarantees
Today

- Use of formal methods in cryptography
  - Prior to 2000 (or Abadi-Rogaway), separate communities
    - Dolev-Yao, spi calculus, BAN logic
  - Security in formal model had little bearing as a security guarantee in the computational model (but attacks in the formal model give real attacks)
  - Soundness guarantees
    - Security in formal models that can be translated to security in computational models
Today

- Use of formal methods in cryptography
  - Prior to 2000 (or Abadi-Rogaway), separate communities
    - Dolev-Yao, spi calculus, BAN logic
    - Security in formal model had little bearing as a security guarantee in the computational model (but attacks in the formal model give real attacks)
  - Soundness guarantees
    - Security in formal models that can be translated to security in computational models
  - Composition: to make analysis of complex protocols feasible; also to obtain security in arbitrary environments
Today

- Use of formal methods in cryptography
  - Prior to 2000 (or Abadi-Rogaway), separate communities
  - Dolev-Yao, spi calculus, BAN logic
  - Security in formal model had little bearing as a security guarantee in the computational model (but attacks in the formal model give real attacks)

- Soundness guarantees
  - Security in formal models that can be translated to security in computational models

- Composition: to make analysis of complex protocols feasible; also to obtain security in arbitrary environments

- On going work: Probabilistic models (e.g. Task PIOA), more tasks, more tools for formal analysis