MoSS:

Modular Security Specifications Framework

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- Many applied protocols are not proven secure
- Admittedly, proving security of applied protocols is challenging
  - Easy to make subtle mistakes
  - Applied protocols and specifications can be complex
  - Reflecting real-world environment assumptions is non-trivial

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MoSS	List of predicates	List of predicates	Yes	No

- **MoSS** *models* are **well-defined** assumptions, including adversary (e.g., MitM), communication (e.g., reliable), synchronization (e.g., bounded-drift clocks), initialization (e.g, shared keys)
- **MoSS** *requirements* are **well-defined** goals, including generic (e.g, indistinguishability) and specific (e.g., authenticated broadcast)

What is MoSS?

- Modular Security Specifications Framework
  - Game-based, with well-defined specifications
- MoSS **separates** the execution process from the *model* under which a protocol is analyzed and the *requirements* that define the protocol's goals.

What is MoSS?

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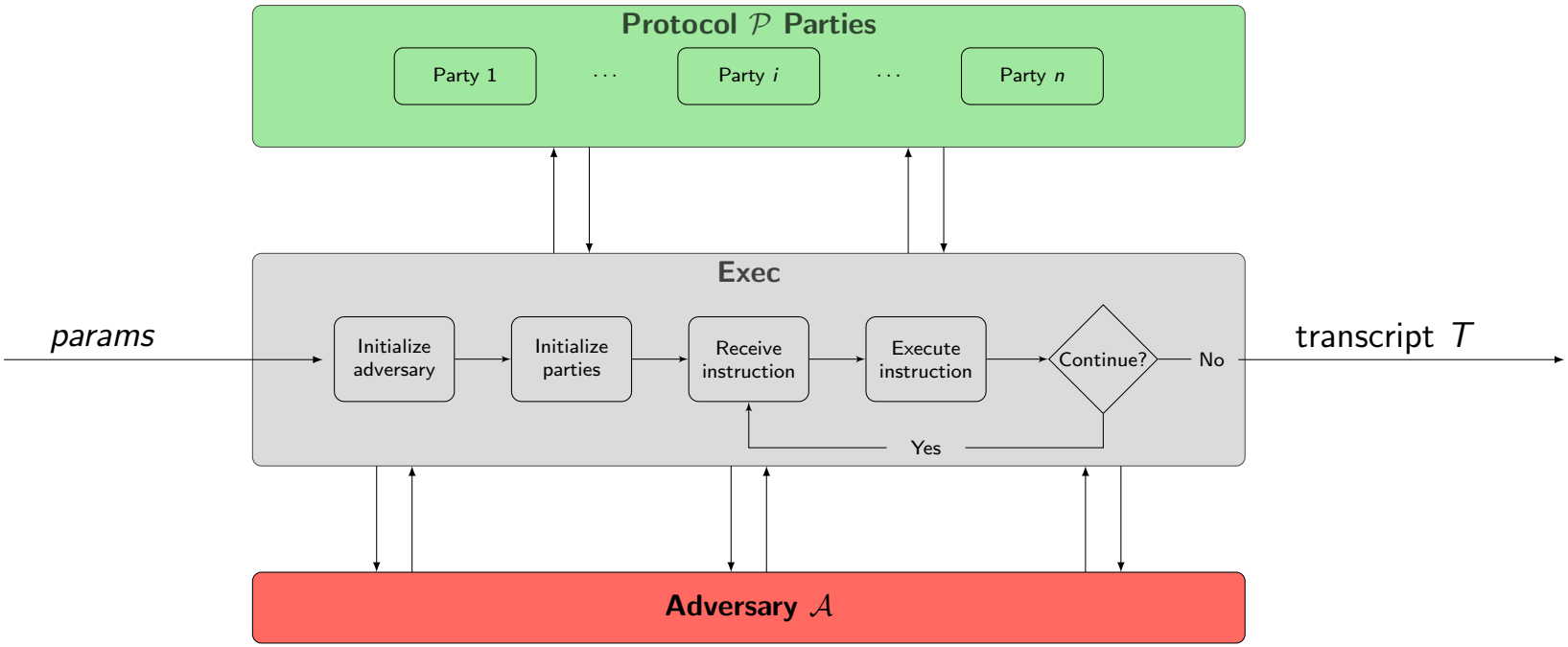
- MoSS **separates** the execution process from the *model* under which a protocol is analyzed and the *requirements* that define the protocol's goals.
- This separation allows:
  - Gradual development of specifications
  - Reusability of definitions and results
  - Simplified and concise analysis

MoSS's Adversary-Driven Execution Process



- Adversary $\mathcal{A}$ and protocol $\mathcal{P}$ are represented as stateless functions
- Execution returns execution transcript T

MoSS's Adversary-Driven Execution Process

1: $(s_{\mathcal{A}}, \mathsf{N}, params.\mathcal{P}[\cdot]) \leftarrow \mathcal{A}[\text{'Init'}](params)$

2: $\forall i \in \mathsf{N}: \; s_i \leftarrow \mathcal{P}[\text{'Init'}](\bot, params.\mathcal{P}[i], \bot)$

3: $e \leftarrow 0$

4: **repeat**

5: $\quad e \leftarrow e + 1$

6: $\quad (ent[e], opr[e], inp[e], clk[e], \tau[e]) \leftarrow \mathcal{A}(s_{\mathcal{A}})$

7: $\quad s^{In}[e] \leftarrow s_{ent[e]}$

8: $\quad (s_{ent[e]}, out[e]) \leftarrow \mathcal{P}[opr[e]](s_{ent[e]}, inp[e], clk[e])$

9: $\quad s^{Out}[e] \leftarrow s_{ent[e]}$

10: $\quad (s_{\mathcal{A}}, out_{\mathcal{A}}, \mathsf{F}) \leftarrow \mathcal{A}(s_{\mathcal{A}}, out[e])$

11: **until** $out_{\mathcal{A}} \neq \bot$

12: $T \leftarrow (out_{\mathcal{A}}, e, \mathsf{N}, \mathsf{F}, ent[\cdot], opr[\cdot], inp[\cdot], clk[\cdot], \tau[\cdot], out[\cdot], params.\mathcal{P}[\cdot], s^{In}[\cdot], s^{Out}[\cdot])$

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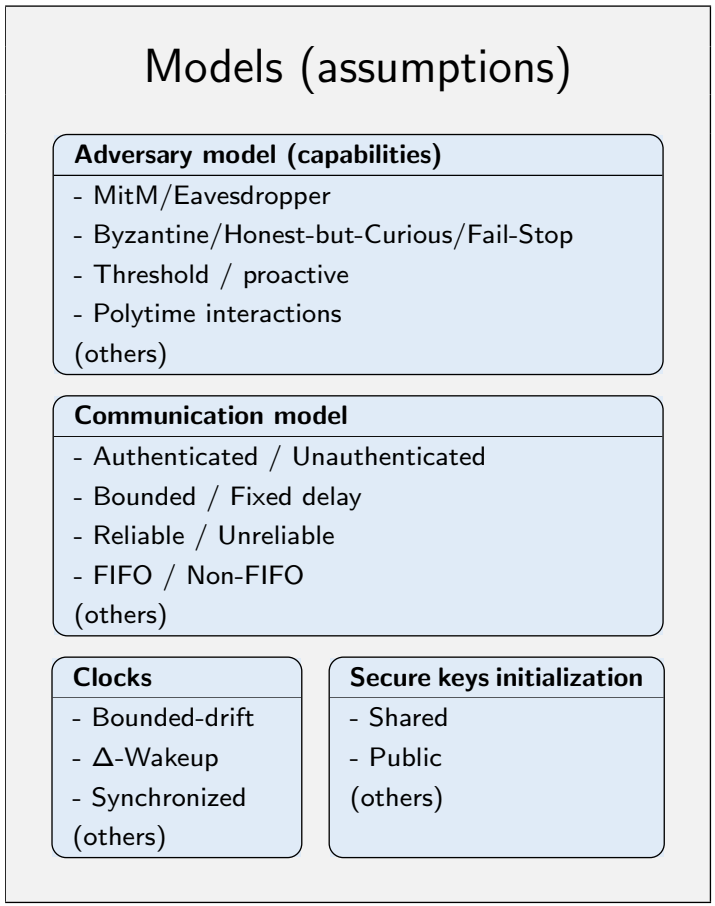
Models



- Check if an adversary **satisfies** a model: $\mathcal{A} \models_{\text{poly}} \mathcal{M}$
- Models are independent
- Can be reused across systems

Models

- A model is a set of pairs (π, β) which we call *specifications*, where π is a predicate and β is the *base function*, which specifies the probability which is allowed for the adversary to win against π

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Definition ($\mathcal{A}$ satisfies $\mathcal{M} = \{(\pi, \beta)\}$)

Adversary $\mathcal{A}$ satisfies model $\mathcal{M} = \{(\pi, \beta)\}$, denoted $\mathcal{A} \models_{\text{poly}} \mathcal{M}$, if for every protocol $\mathcal{P}$, the probability that $\pi(T, \mathit{params}) = \perp$ is at most negligibly greater than $\beta(\mathit{params})$, where $T \leftarrow \mathbf{Exec}_{\mathcal{A},\mathcal{P}}(\mathit{params})$.

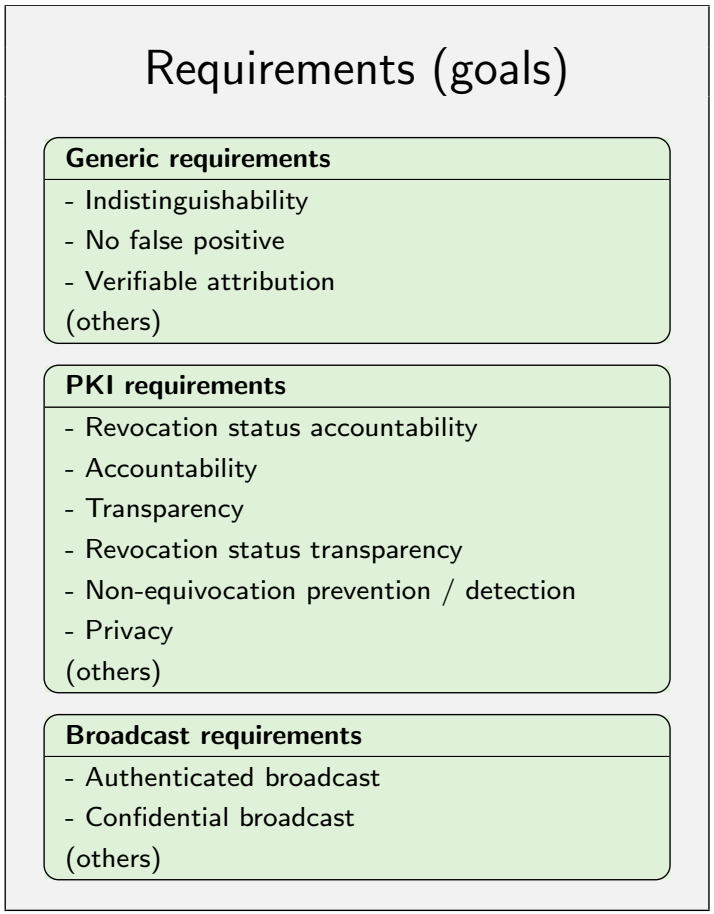
Example Model

- Bounded clock drift model $\mathcal{M}^{\text{Drift}}_{\Delta_{clk}} = \{(\pi^{\text{Drift}}_{\Delta_{clk}}, 0)\}$

Algorithm 1 Bounded clock drift model predicate $\pi^{\text{Drift}}_{\Delta_{clk}}(T, params)$

1: **return** (
2: $\quad \forall \hat{e} \in \{1, \ldots, T.e\}$: ▷ *For each event*
3: $\quad\quad |T.clk[\hat{e}] - T.\tau[\hat{e}]| \leq \Delta_{clk}$ ▷ *Local clock is within Δ_{clk} drift from real time*
4: $\quad\quad$ **and if** $\hat{e} \geq 2$ **then** $T.\tau[\hat{e}] \geq T.\tau[\hat{e}-1]$ ▷ *In each consecutive event, the real time difference is monotonically increasing*
)

Requirements



- Check if a protocol satisfies a **requirement** under a **model**: $\mathcal{P} \models^{\mathcal{M}}_{\text{poly}} \mathcal{R}$
- Requirements are well-defined using predicates
- Comparable

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Protocol $\mathcal{P}$ satisfies requirement $\mathcal{R} = \{(\pi, \beta)\}$ under model $\mathcal{M}$, denoted $\mathcal{P} \models^{\mathcal{M}}_{\text{poly}} \mathcal{R}$, if for every adversary $\mathcal{A}$ which satisfies $\mathcal{M}$, the probability that $\pi(T, \mathit{params}) = \perp$ is at most negligibly greater than $\beta(\mathit{params})$, where $T \leftarrow \mathbf{Exec}_{\mathcal{A},\mathcal{P}}(\mathit{params})$.

Example Requirement

- Δ-transparency requirement $\mathcal{R}_{\Delta\text{TRA}} = \{(\pi_{\Delta\text{TRA}}, 0)\}$

Intuitive definition (Δ-transparecy)

A certificate attested as Δ-transparent must be available to all 'interested' parties within Δ time of its transparency attestation being issued by a proper authority.

$$\pi_{\Delta\text{TRA}}(T, params) \equiv \left\{ \begin{array}{l} (\psi, \rho, pk, \iota, \iota_M) \leftarrow T.out_{\mathcal{A}}; \\ \textbf{return } \neg \left[\begin{array}{l} \textsc{HonestEntity}(T, params, \iota) \wedge \\ \textsc{CorrectPublicKey}(T, params, \iota, pk, \rho.\iota) \wedge \\ \textsc{ValidCertificateAttestation}(T, params, \{\Delta\text{TRA}\}, \psi, pk, \rho) \wedge \\ \textsc{HonestEntity}(T, params, \iota_M) \wedge \\ \textsc{IsMonitor}(T, params, \iota_M, \rho.\iota) \wedge \\ \textsc{HonestMonitorUnawareOfCertificate}(T, params) \wedge \\ \textsc{WasNotAccused}(T, params) \end{array} \right]; \end{array} \right\}$$

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Lemma (Requirement-model monotonicity lemma)

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Lemma (Requirements union lemma)

For any models $\mathcal{M}, \mathcal{M}'$ and any requirements $\mathcal{R}, \mathcal{R}'$, let $\widehat{\mathcal{M}} \equiv \mathcal{M} \cup \mathcal{M}'$ and $\widehat{\mathcal{R}} \equiv \mathcal{R} \cup \mathcal{R}'$. Then:

$$\left(\mathcal{P} \models^{\mathcal{M}}_{\text{poly}} \mathcal{R} \wedge \mathcal{P} \models^{\mathcal{M}'}_{\text{poly}} \mathcal{R}'\right) \Rightarrow \mathcal{P} \models^{\widehat{\mathcal{M}}}_{\text{poly}} \widehat{\mathcal{R}}$$

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- See paper for more lemmas

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  1. Prove that $\mathcal{P}$ ensures authenticity assuming a secure shared-key initialization model.
  2. Then, show that $\mathcal{P}$ also achieves freshness when we also assume bounded clock drift.
  3. Lastly, show that $\mathcal{P}$ ensures a bounded delay by additionally assuming bounded-delay communication.

MoSS Can Do Much More

- Extendable execution process
  - Entity corruptions, confidentiality, shared keys, etc.
- Built-in support for concrete security
  - Important to use concrete parameter values in practice
- Allows to ensure polynomial-time execution
  - Not trivial due to interaction, unlimited invocations, state

Future Work

- Modular specifications and compositions
  - Both modular specifications and modular protocol design, i.e., provably-secure compositions
- Modular simulation-based specifications
  - Modular specifications in simulation-based framework(s) and/or support for simulation-based specifications in MoSS
- Computer-aided analysis
  - Translating MoSS specifications to other forms and/or developing tools for MoSS directly

Conclusions

- MoSS facilitates modular security specifications of cryptographic and other protocols
- Allows provable security for practical crypto/security protocols, with complex models (delays, faults, etc.)
- Allows reuse of models, requirements
- Paper contains details, proofs and more, e.g., concrete-security