Network Security Analysis via Predicate Logic

&

Increasing Trustworthiness: A case study in Theorem Prover Design

CS3234

Lecture 7

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Network Security Analysis via Predicate Logic

Process for applying theory to practice

1. Learn about problem

2. Create a formal model of the problem

3. State the goal

4. Use some kind of tool (theorem prover, SAT solver, etc.) to solve

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Problem

- We have a network of many computers (100s-1,000s-10,000s)
- Each computer only allows certain kinds of connections (example: the accounting computer only allows the CEO's computer to access it; anyone in the world can access the http services of the web server)
- Each computer is running different kinds of software
  - Mail software
  - Sales software
  - Office software
  - Web hosting software
  - etc.
- Often different computers are running different versions, different patches, etc.

Problem

We wish to guarantee some security policy, such as:

- Only the CEO can access at the accounting data

How can we try to do this?

Fact: most security breaches are exploits of known vulnerabilities. Defending against truly new vulnerabilities is really hard, so let's concentrate on the common case.

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Why do you take CS courses?

In this class, we are teaching you a set of tools

- Propositional Logic
- SAT Solving
- Natural Deduction
- Theorem Proving
- Predicate Logic
- Modal Logic
- Temporal Logic
- Model Checkers
- Hoare Logic

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… but figuring out which tools can help in which situations is <u>hard</u> (knowing the tools well is a prerequisite, which is why you take courses…)

Usually you have to study a problem for some time before you get a good idea.

Model

- We will model the network with a series of implications (essentially how an attacker would break our policy)

- We have two basic classes of rules:
  - Network topology
  - Attack vulnerability

- Example rules (network topology):
  - forall (p : computer), AccessHTTP(p, WebServerComputer)
  - …
  - RunningApache1.0(WebServerComputer)
  - …

More rules

- Attack vulnerability rule:
  - …
  - KnownAttack42: forall (p1 : computer) (p2 : computer), RunningApache1.0(p2) -> AccessHTTP(p1,p2) -> TakeOver(p1,p2)
  - …

Uh oh…

It appears that anyone can take over the webserver!

More rules

– …

– TakeOver(CEOComputer, AccountingComputer)

– …

The CEO likes direct access to the accounting computer so that he can see the latest sales results.

More rules

- …
- AccessReportTool(WebServerComputer, CEOComputer)
- …

The CEO likes to get regular reports and statistics from his webserver, so he uses AccessReportTool, which is this really great piece of software, to do this.

More rules

- …
- KnownAttack212: forall p1 p2,
  AccessReportTool(p1,p2) -> TakeOver(p1,p2)
- …

Unfortunately, he downloaded it from a hacker website...

How to hack the accounting computer (and why an evildoer would want to)

1. Access the webserver:
   - forall (p : computer), AccessHTTP(p, WebServerComputer)

2. Since the webserver is running an old version of Apache, take it over:
   - RunningApache1.0(WebServerComputer)
   - KnownAttack42: forall (p1 : computer) (p2 : computer), RunningApache1.0(p2) -> AccessHTTP(p1,p2) -> TakeOver(p1,p2)

3. Since the CEO is nice enough to have installed AccessReportTool and let it access his machine, use it to take it over:
   - AccessReportTool(WebServerComputer, CEOComputer)
   - KnownAttack212: forall p1 p2, AccessReportTool(p1,p2) -> TakeOver(p1,p2)

4. Since the CEO likes direct access to the accounting computer, you can now take over the accounting computer
   - TakeOver(CEOComputer, AccountingComputer)

5. Transfer money to secret bank account

6. Flee country

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Goal

What you want to show is that:

forall p, p <> CEOComputer ->

~TakeOver(p, AccountingComputer)

This is one way to formally state the policy; as the policy gets more complicated it gets harder to state it…

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5. Building a business…

- Network Topology
  - Which connections different computers accept
  - This must be determined by some kind of network analysis tool, maybe that you run each night

- Known Attacks
  - Distributed by some security firm (think antivirus software)

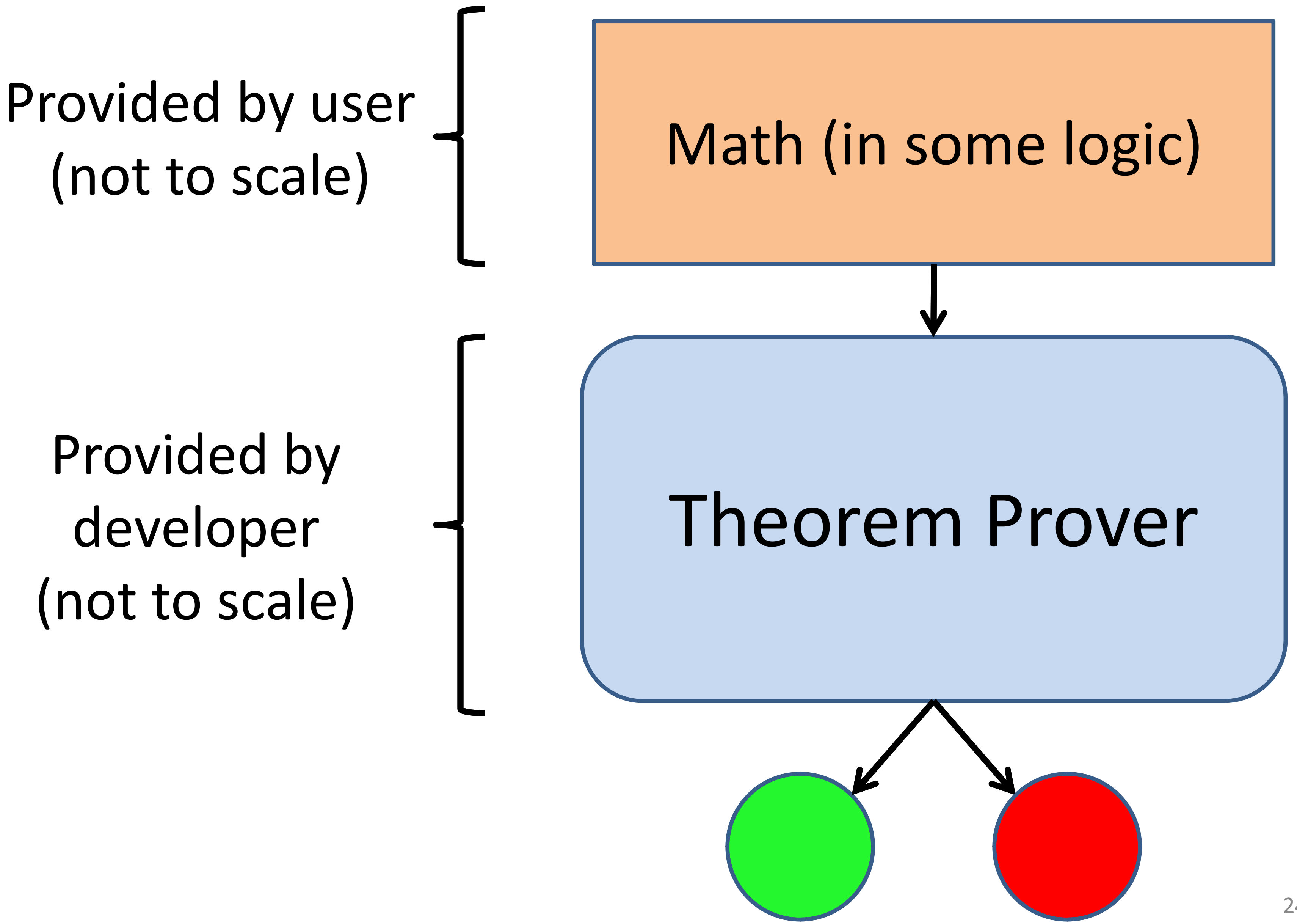
(unfortunately, other people have already patented this idea…)

Something completely different…

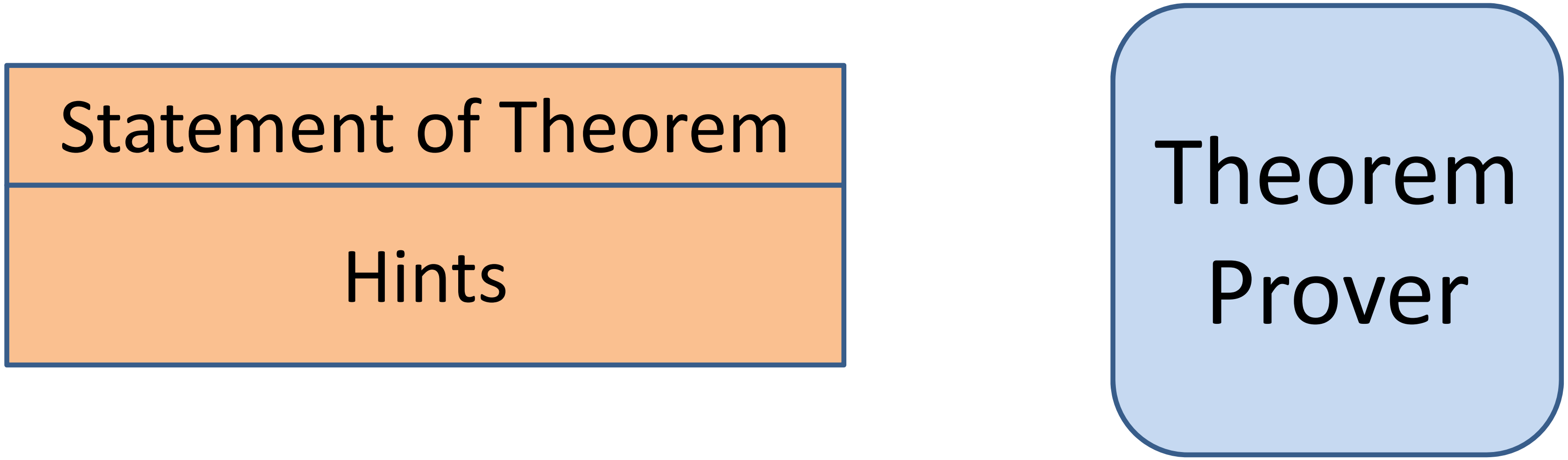
How do we build a trustworthy system?

(a case study)

Theorem Prover Overview



Misleading Scales



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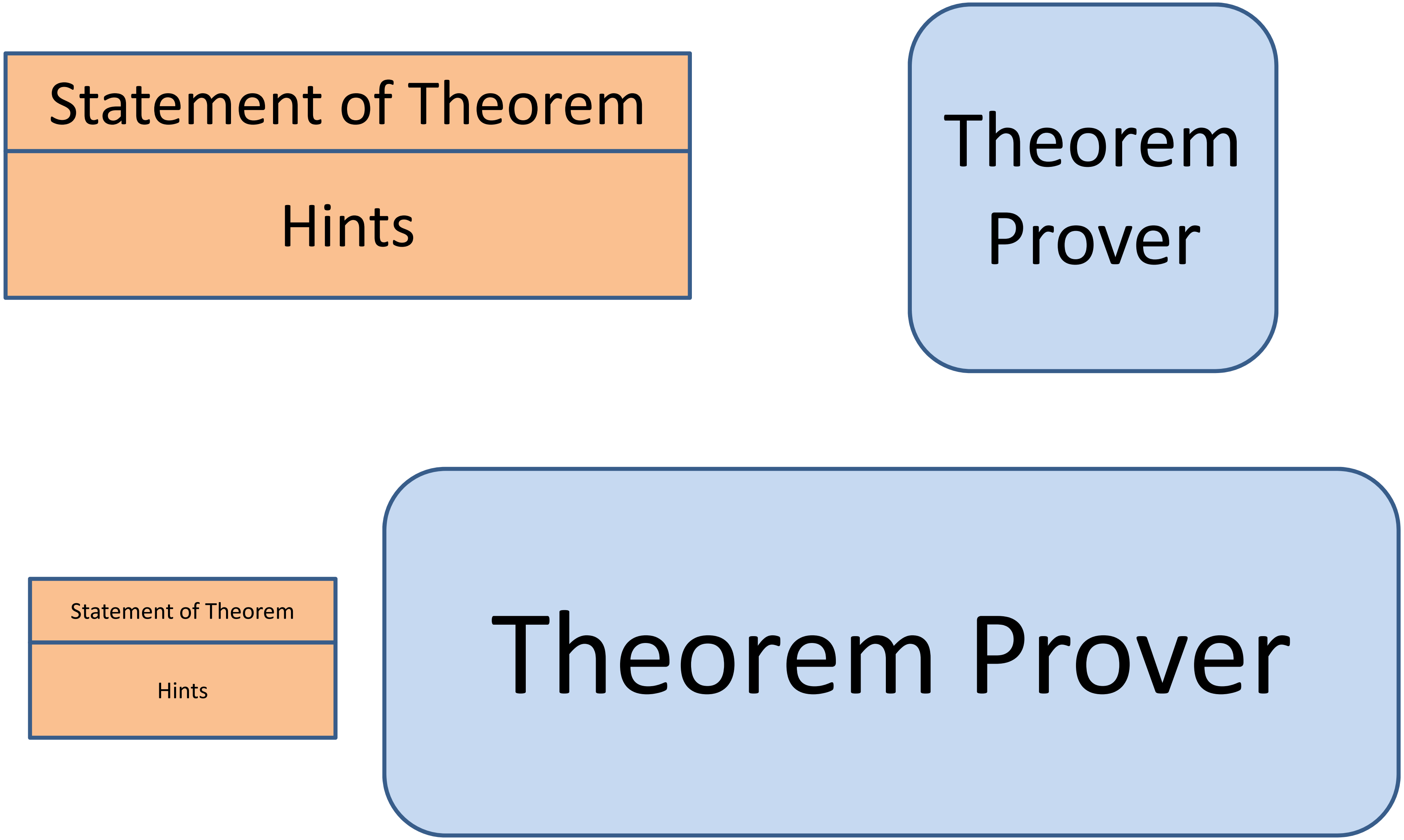
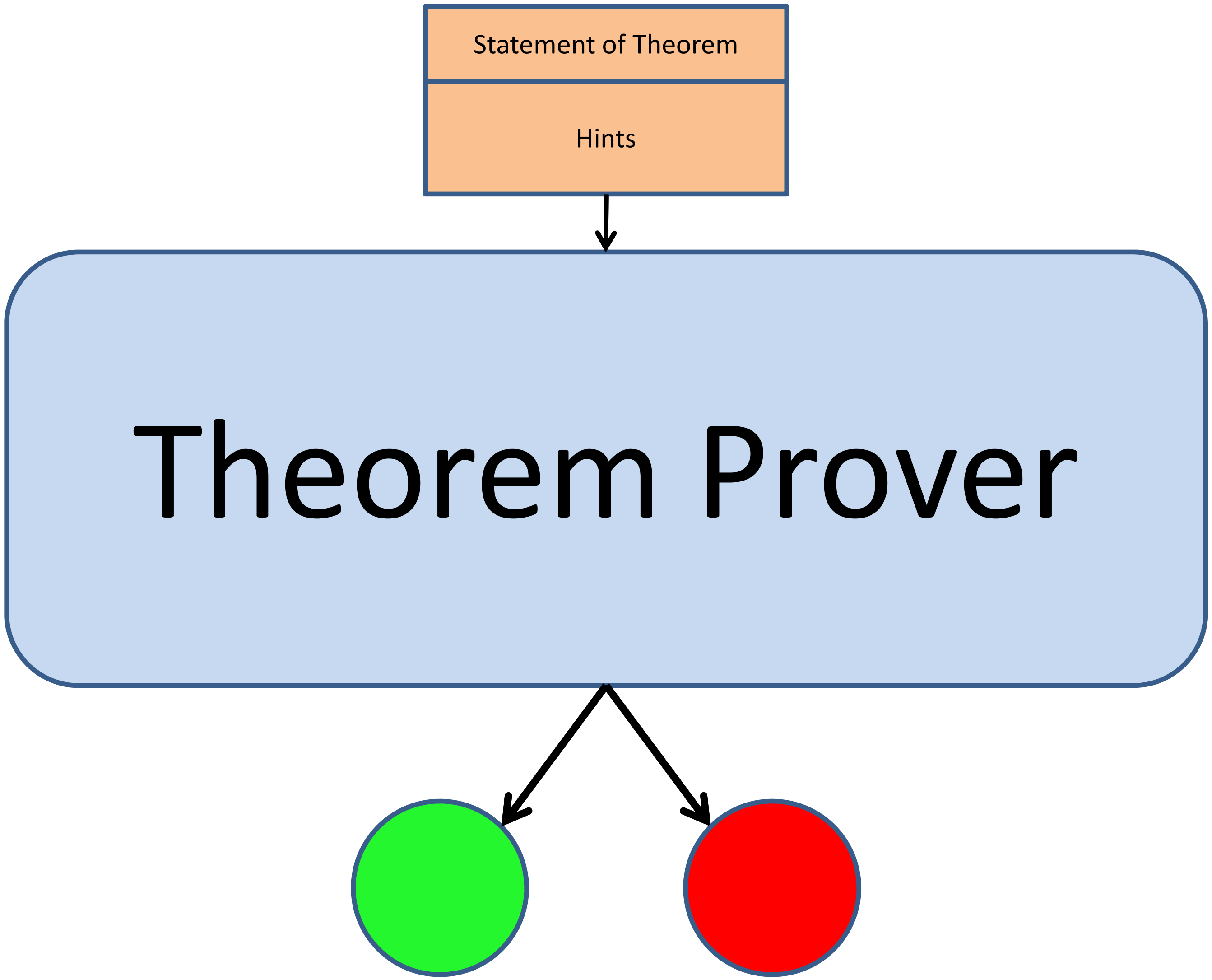


Trustworthiness

What kinds of things lead to increased trust?

- Complexity: simpler things better!
- Size: smaller things better!
- Stability: constant things better!
- Mechanically verified: much better!

Increasing Confidence



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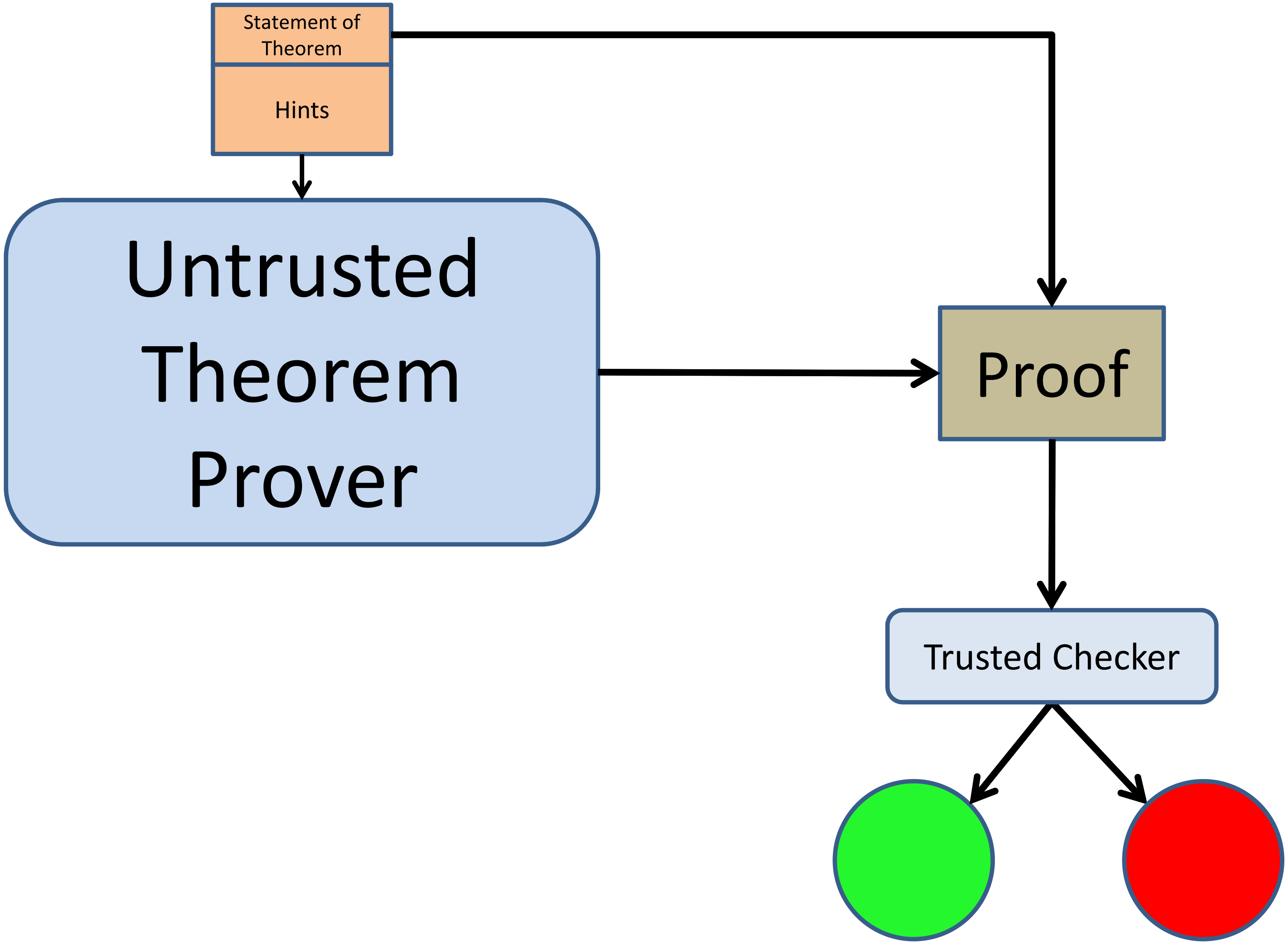
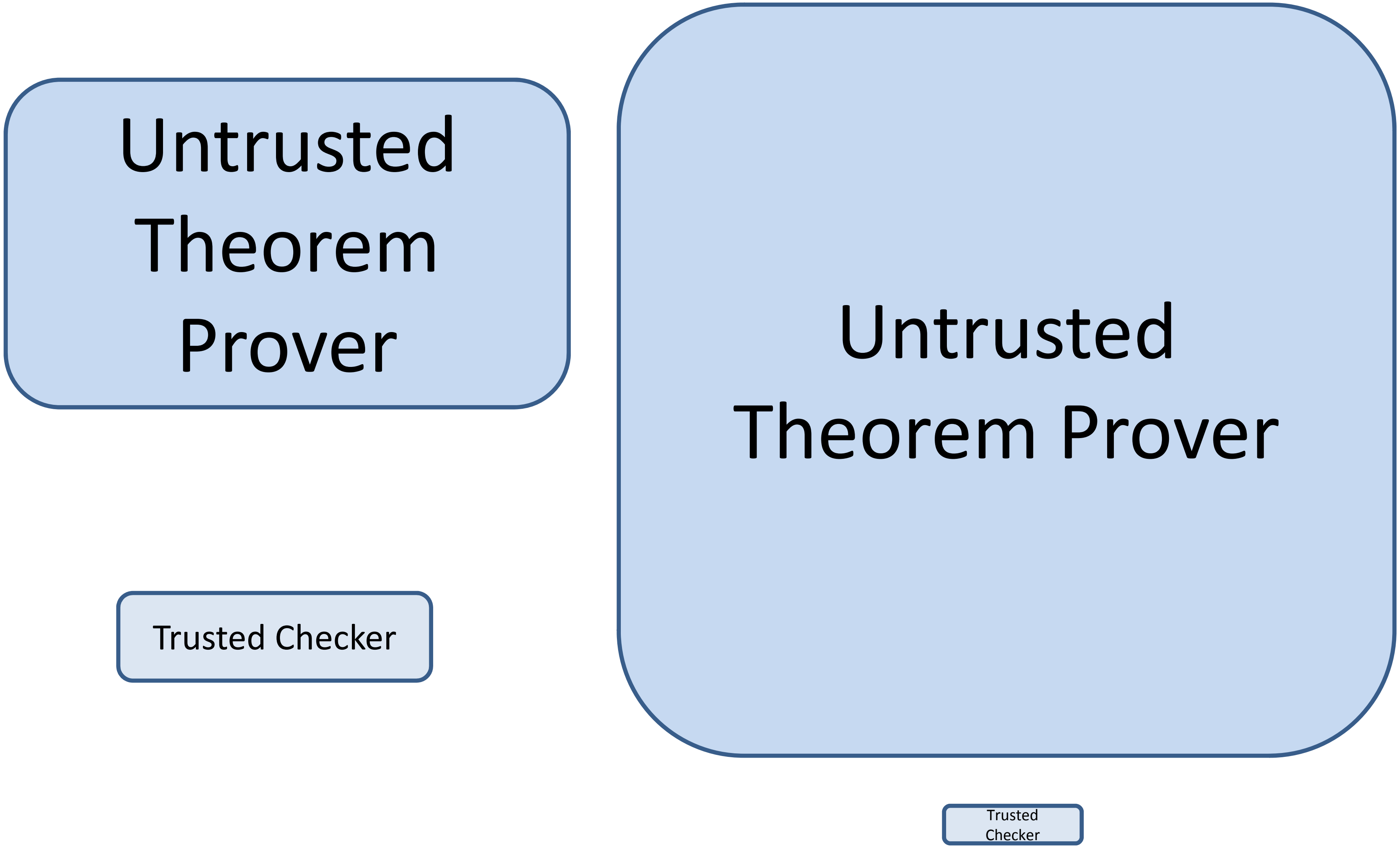


Misleading Scales

Untrusted Theorem Prover

Trusted Checker

Misleading Scales



Theorem Prover

- Generates proof from hints
- Frequently updated with new features
- Can be large (as large or larger than a compiler, 200k+ lines)
- Does not have to be trusted

Checker

- Checker is very:
  – Simple
  – Stable
  – Small
  – Verified by humans very carefully

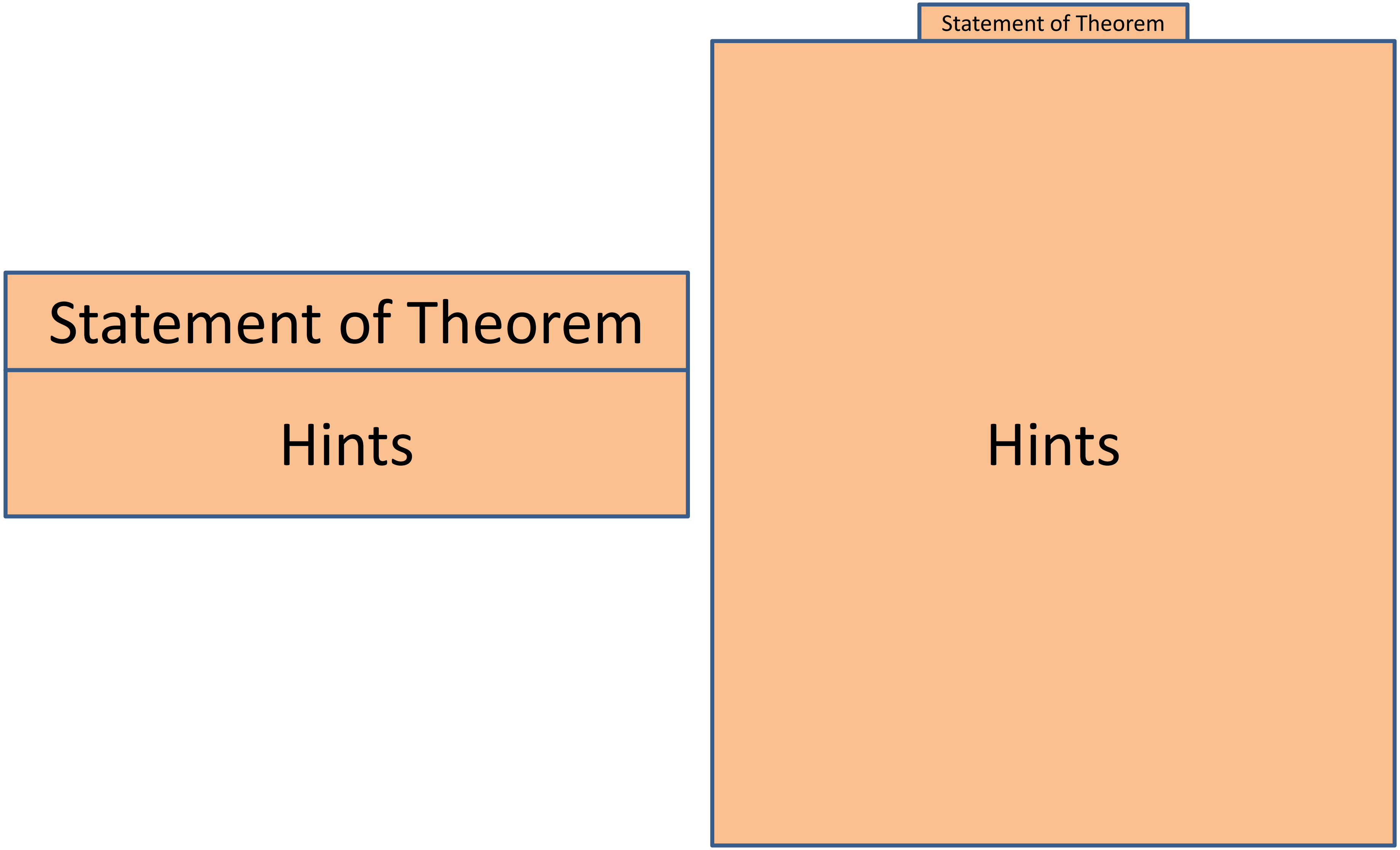
- Smallest known checker for HOL around 800 lines of C with no library support
  – Included parser and simple Prolog interpreter

Misleading Scales

Statement of Theorem

Hints

Misleading Scales



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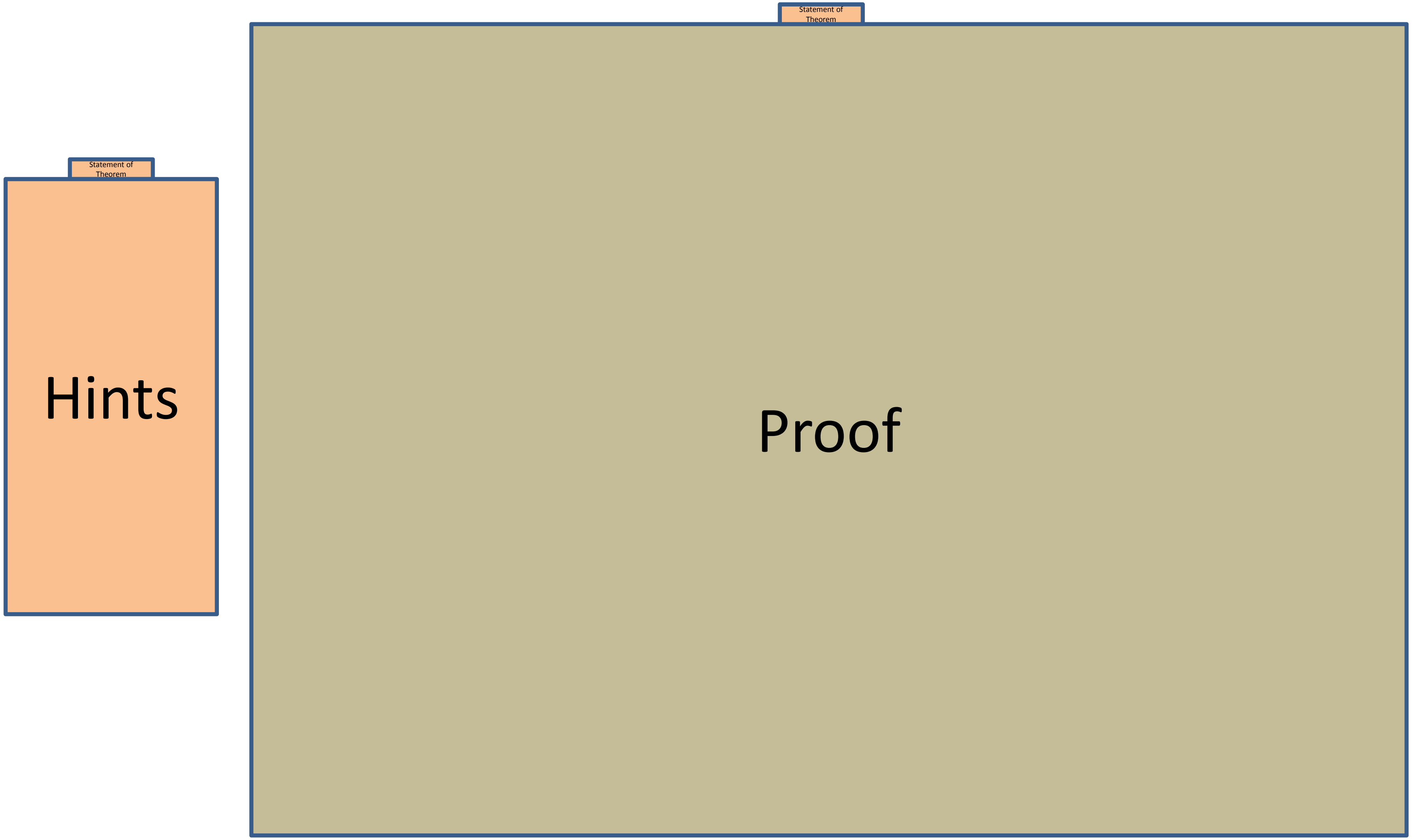

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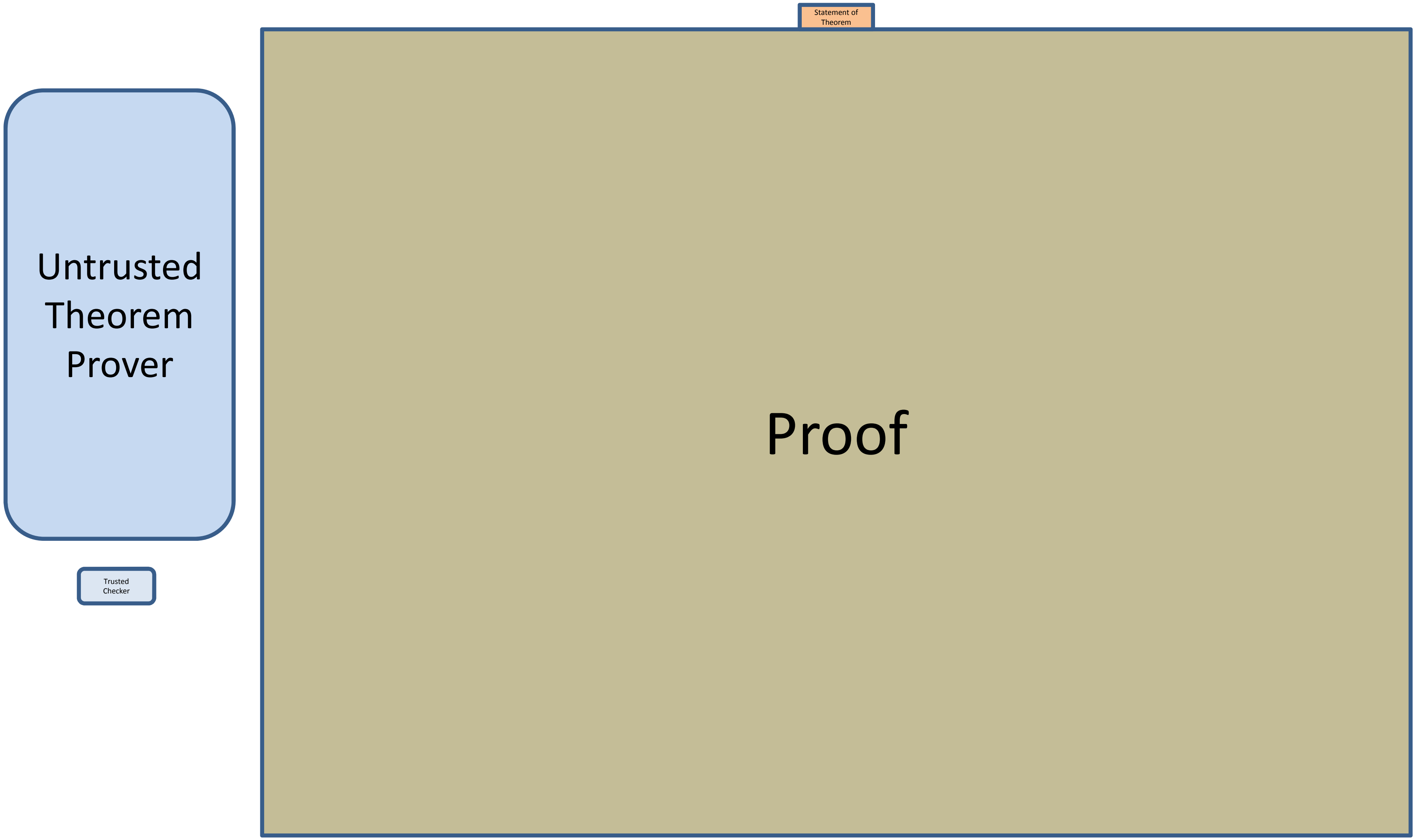

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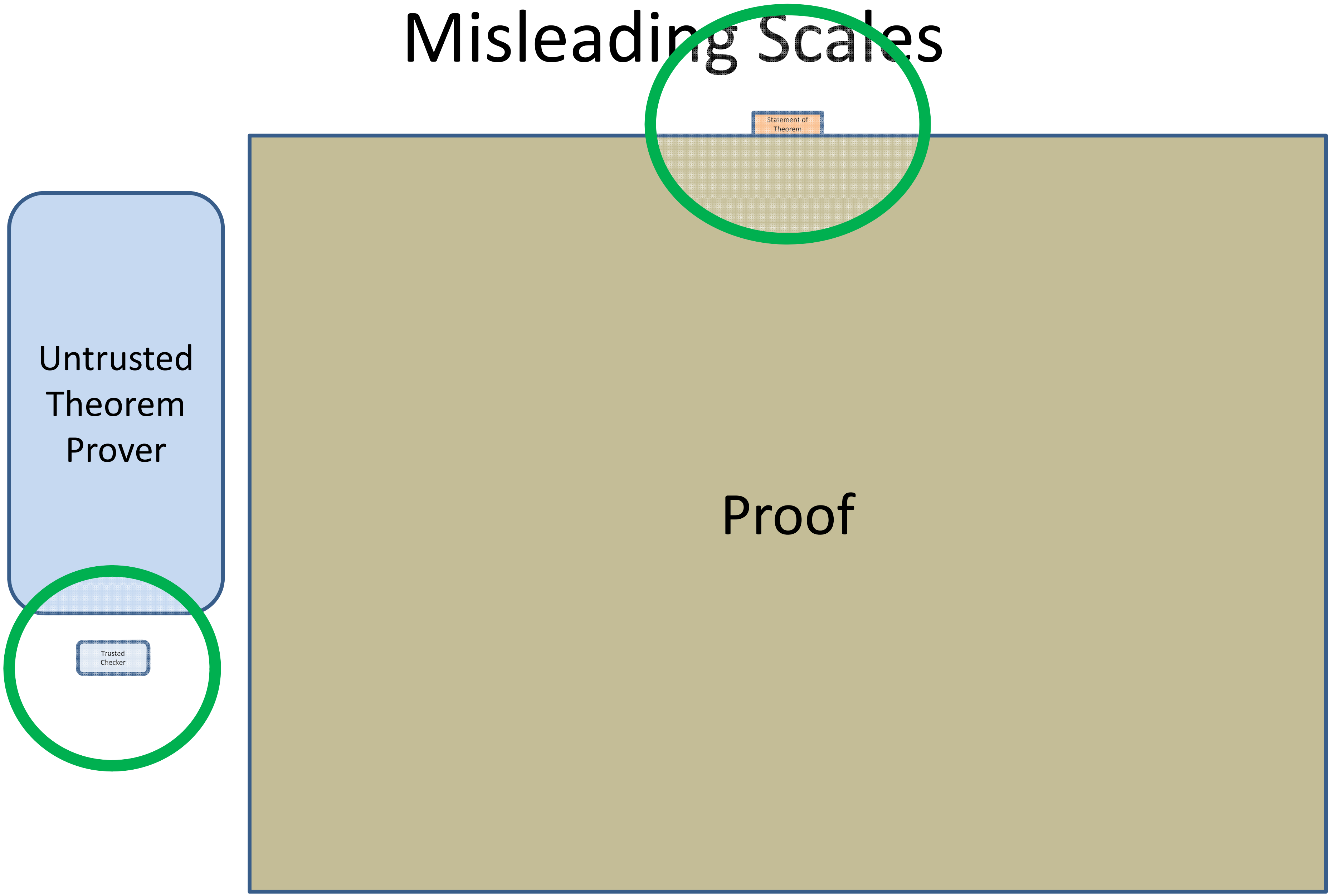

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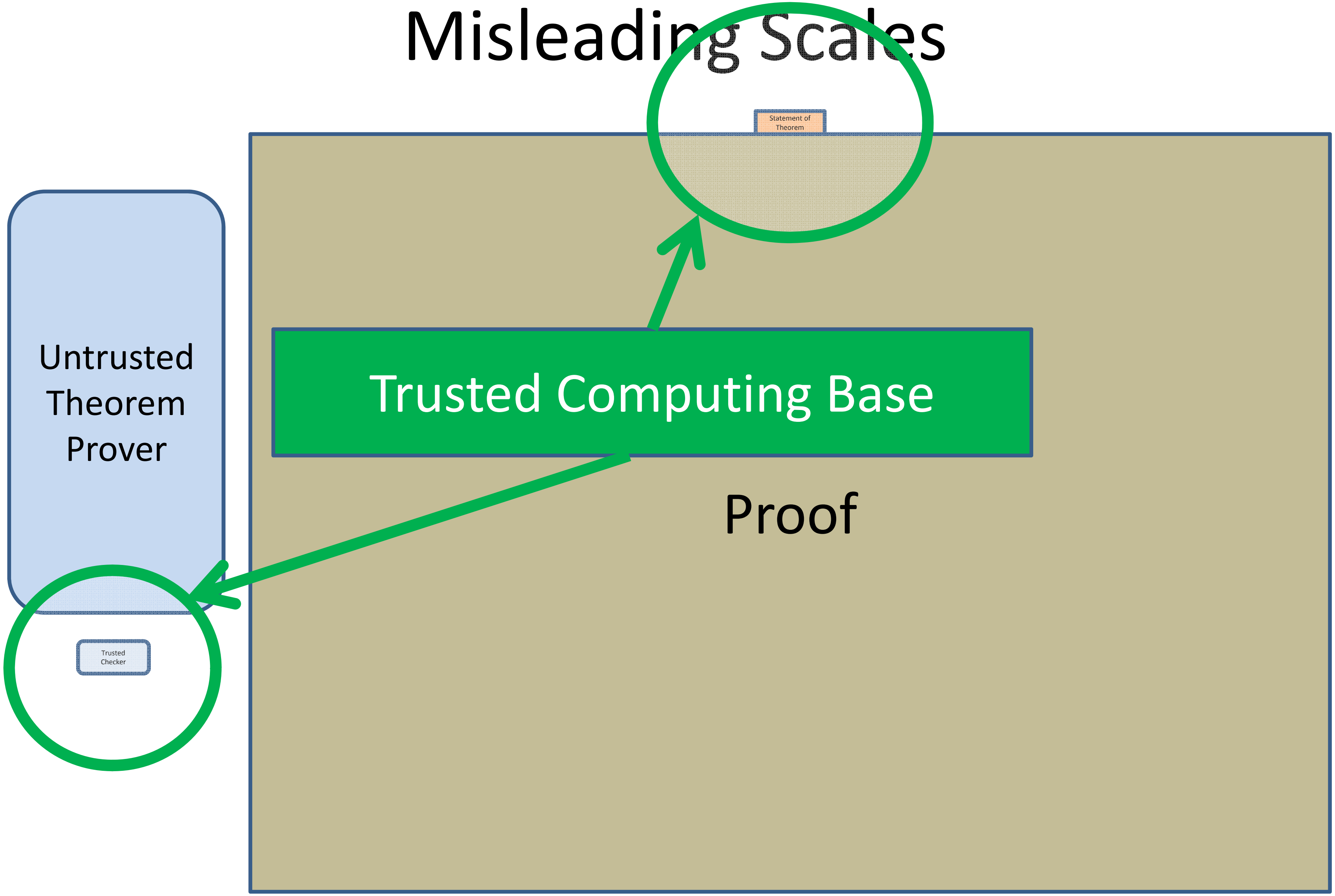


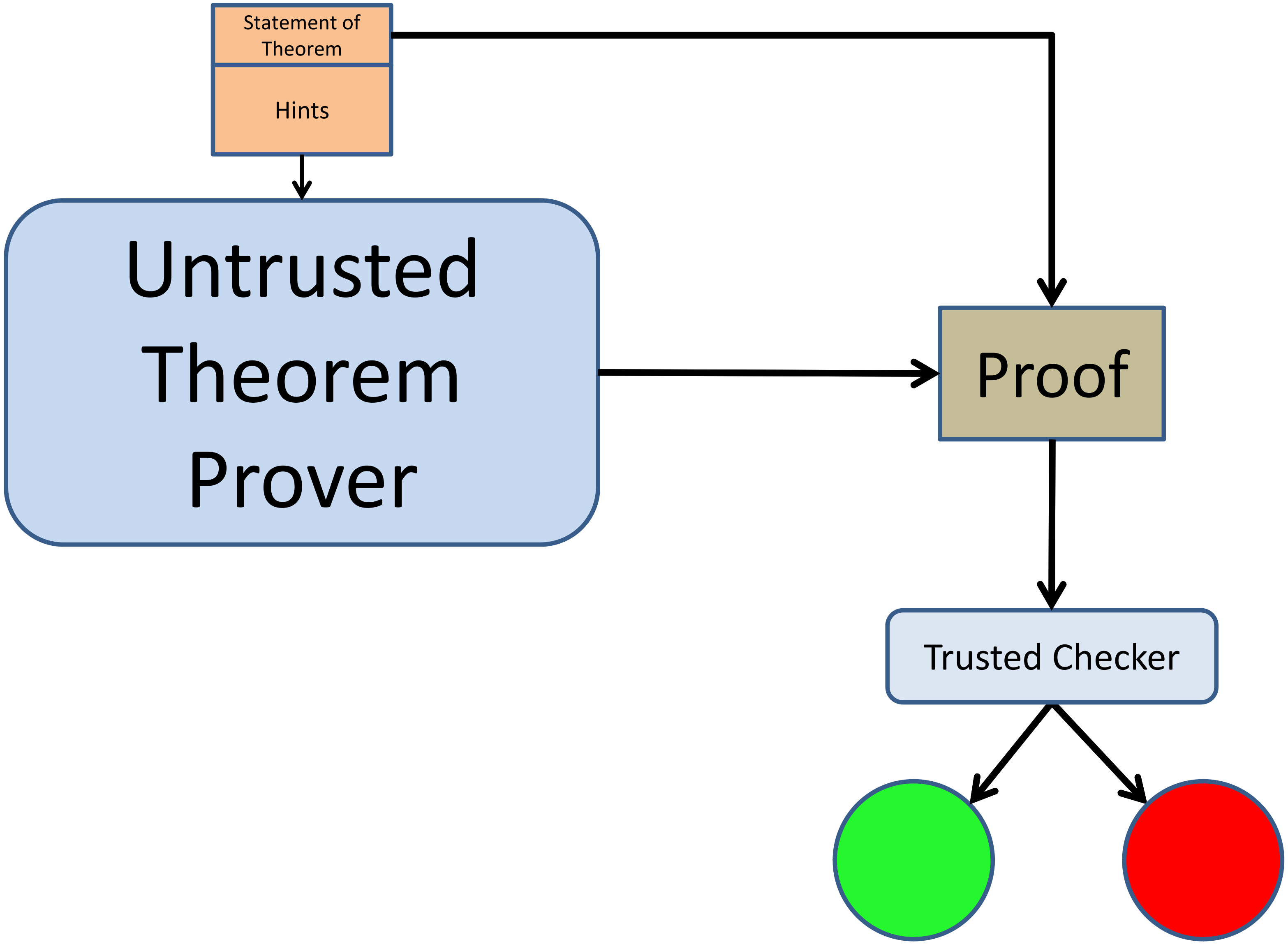
Trusted Computing Base

- The only things that have to be trusted:
  - Checker
  - Statement of theorem

- Everything else (hints, library, theorem prover, proof) does not

- Possible to get 3+ orders of magnitude difference in size (1000x) between trusted and untrusted

Review


Statement of Theorem
Hints
Untrusted Theorem Prover
Proof
Trusted Checker