Verifying remote computations using PCPs

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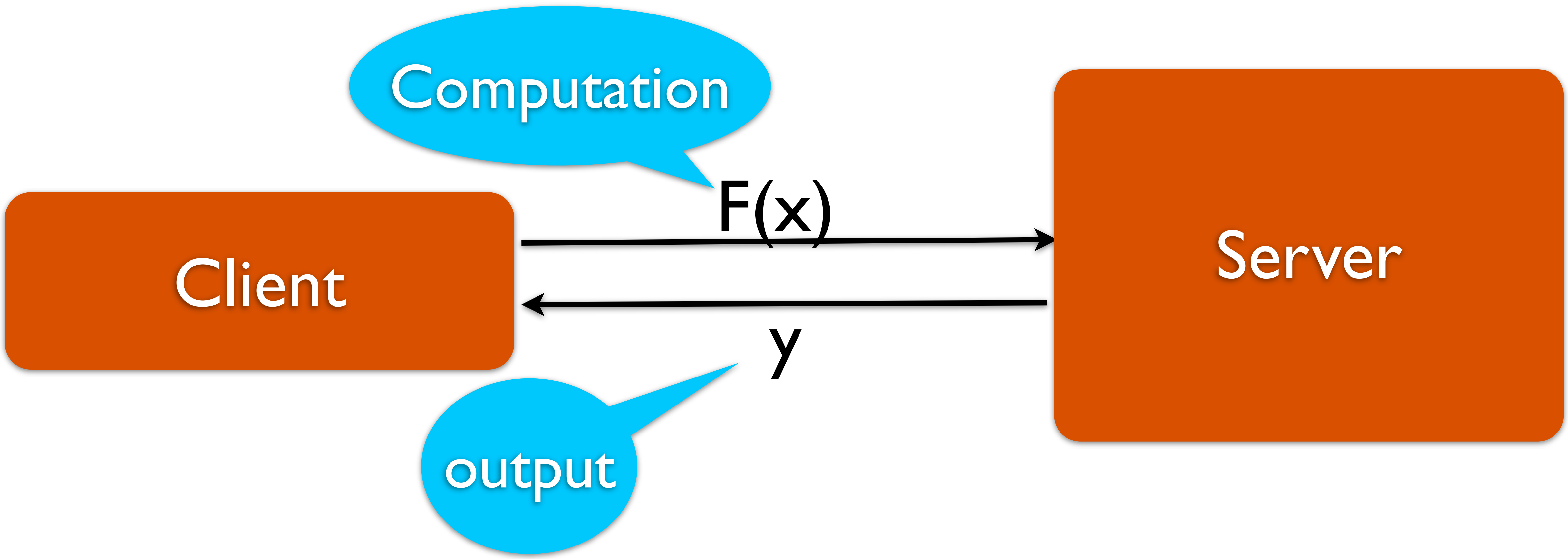
Can we build this?



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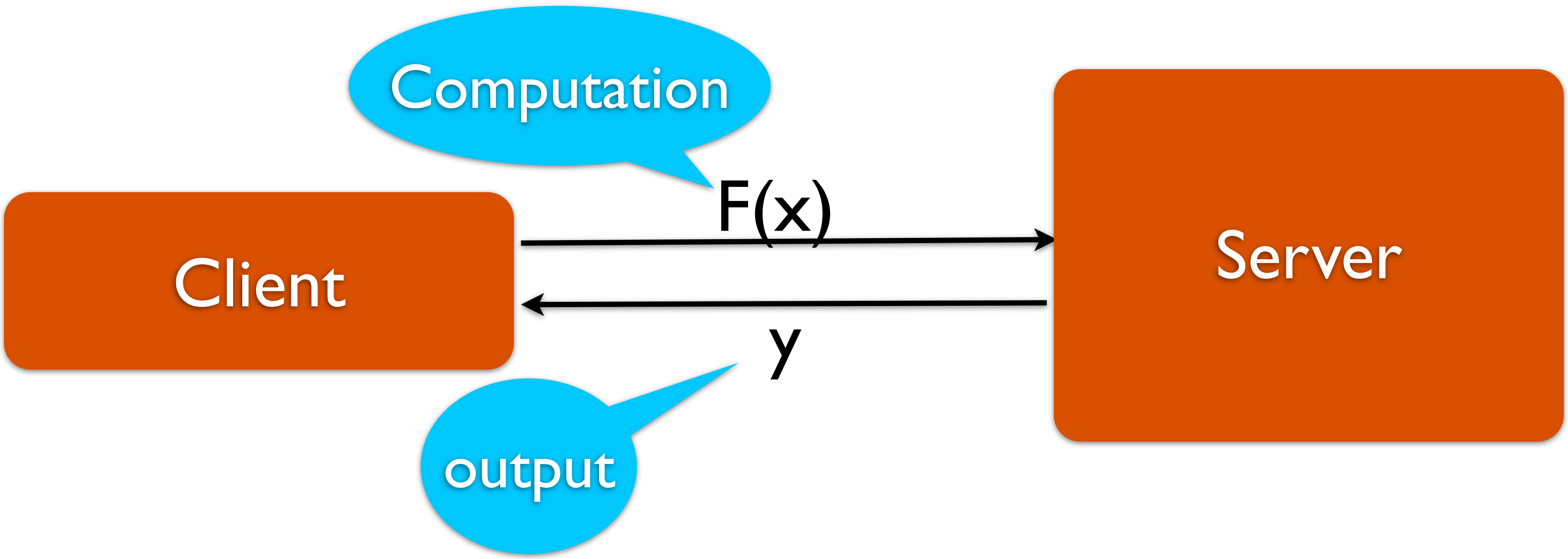

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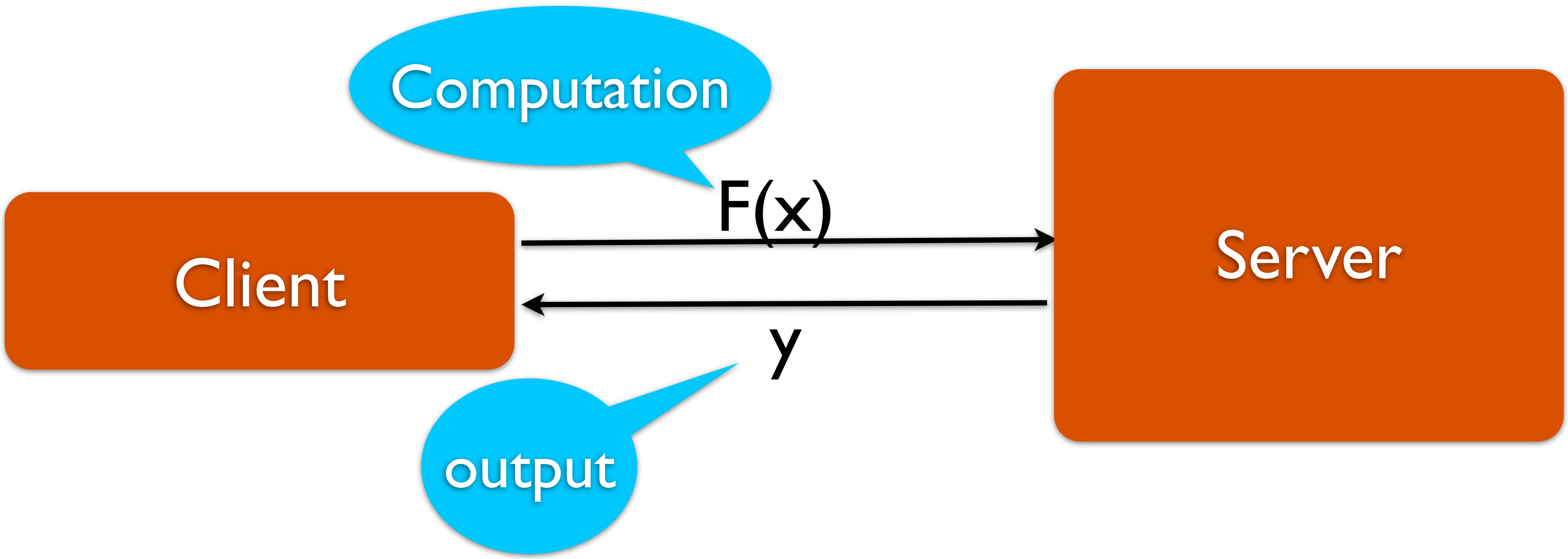

- Check if y equals F(x) without re-executing
- Unconditional: no assumptions

Why should we build this?

- Offloading computations to the cloud
- Outsourcing computations to volunteer machines (Enigma@home, Einstein@home, ...)

How can we solve this problem in principle?

- Probabilistically checkable proofs (PCPs) and argument systems [Arora et al. JACM, 1998]

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- PCP theorem: server proves that y = F(x) and client validates without re-executing

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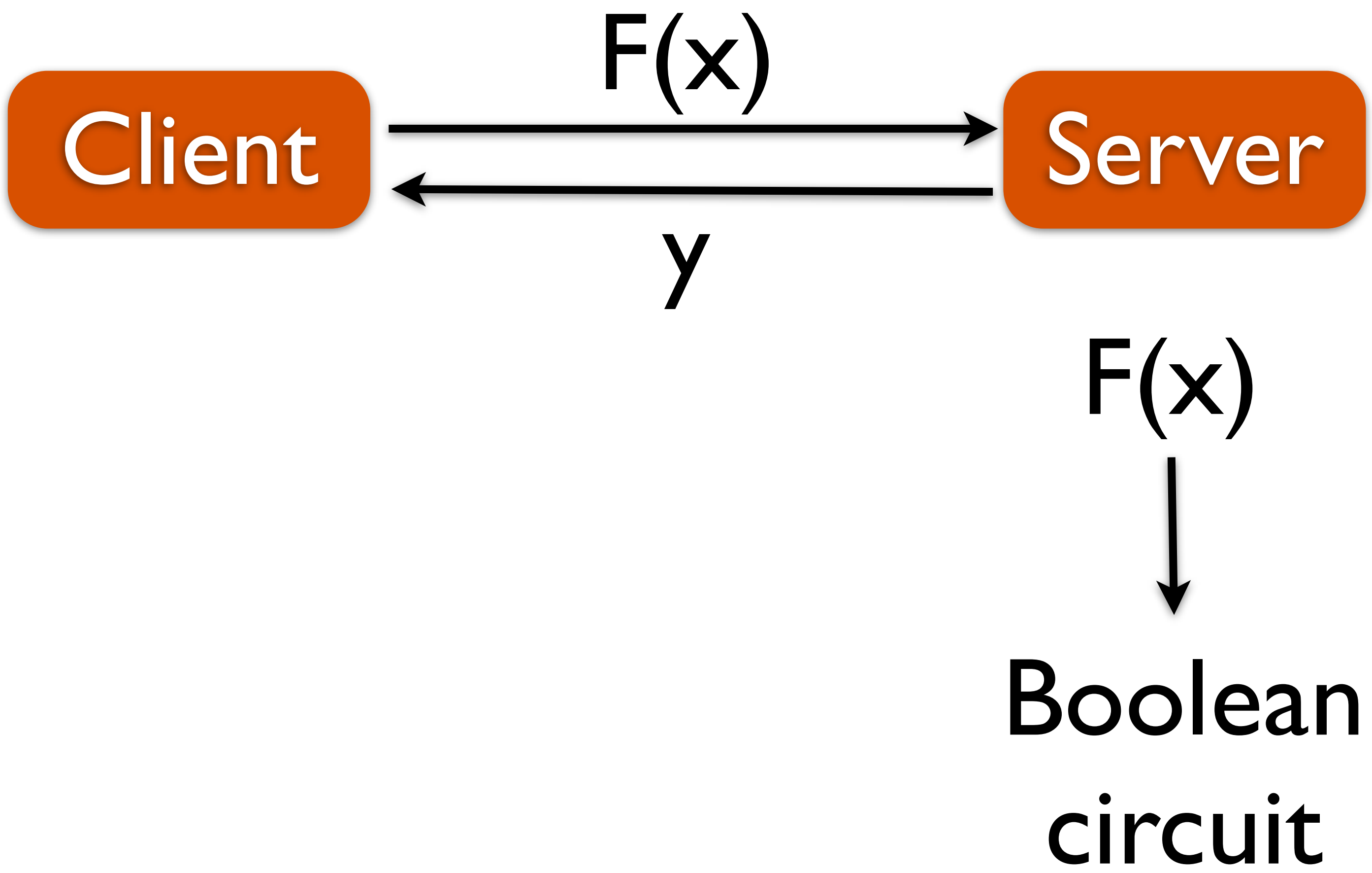
- But the costs are also mind-blowing
  - For polynomial evaluation (700 variables), the server takes 10^5 years!
- Our research program: try to make PCPs practical

Rest of this talk:

- Overview of PCPs
- Our refinements

PCPs from 200,000 feet



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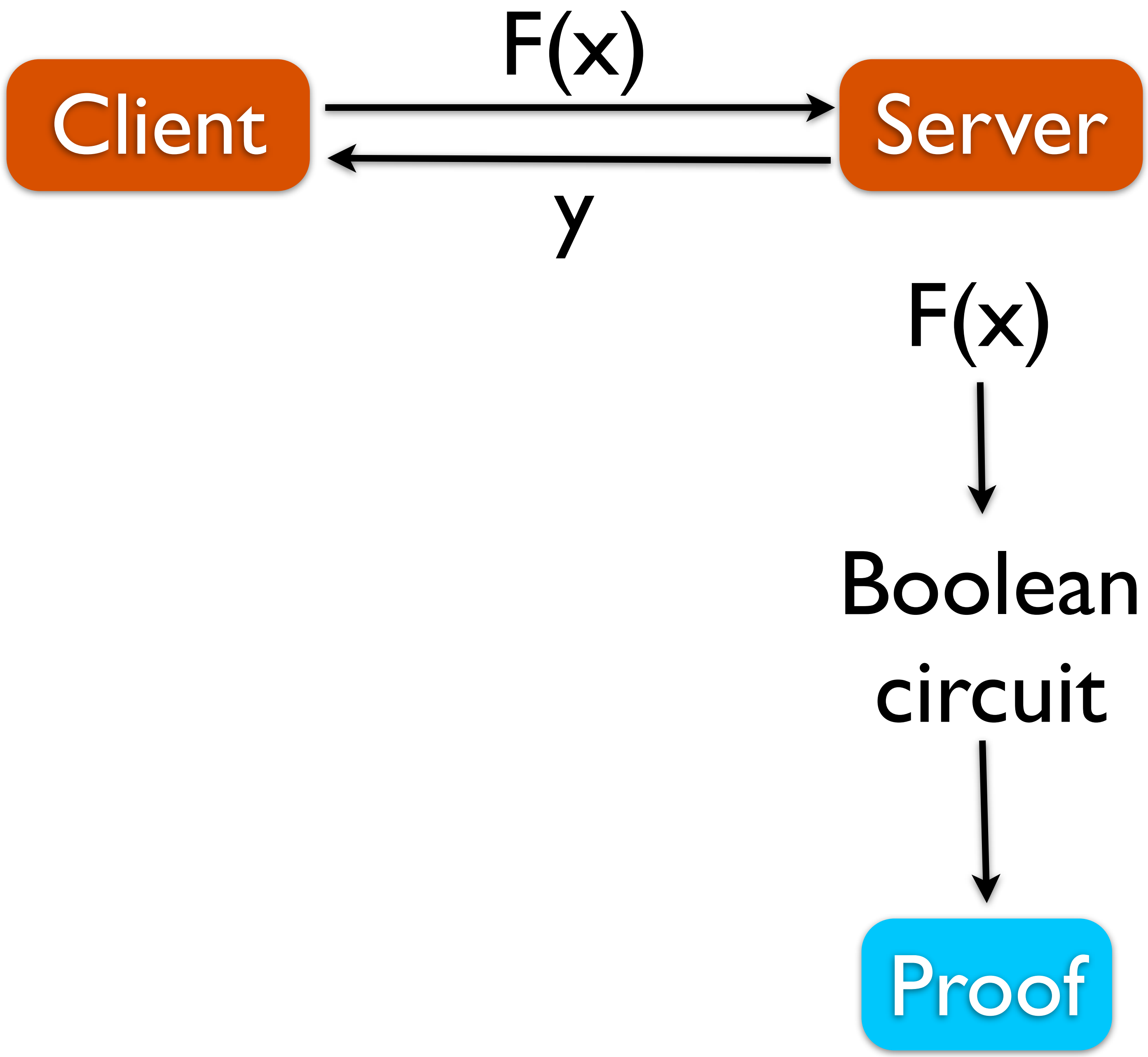

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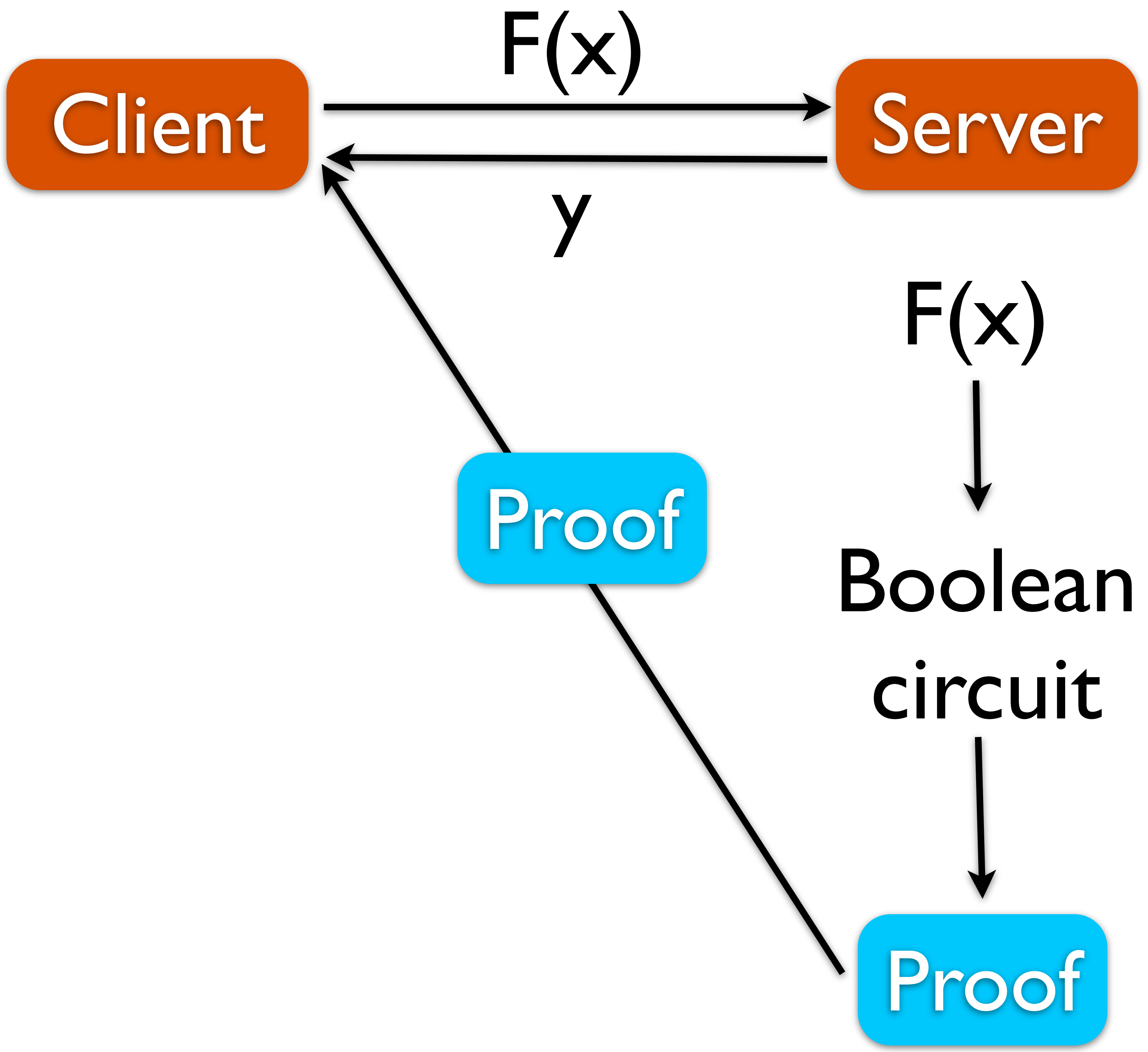

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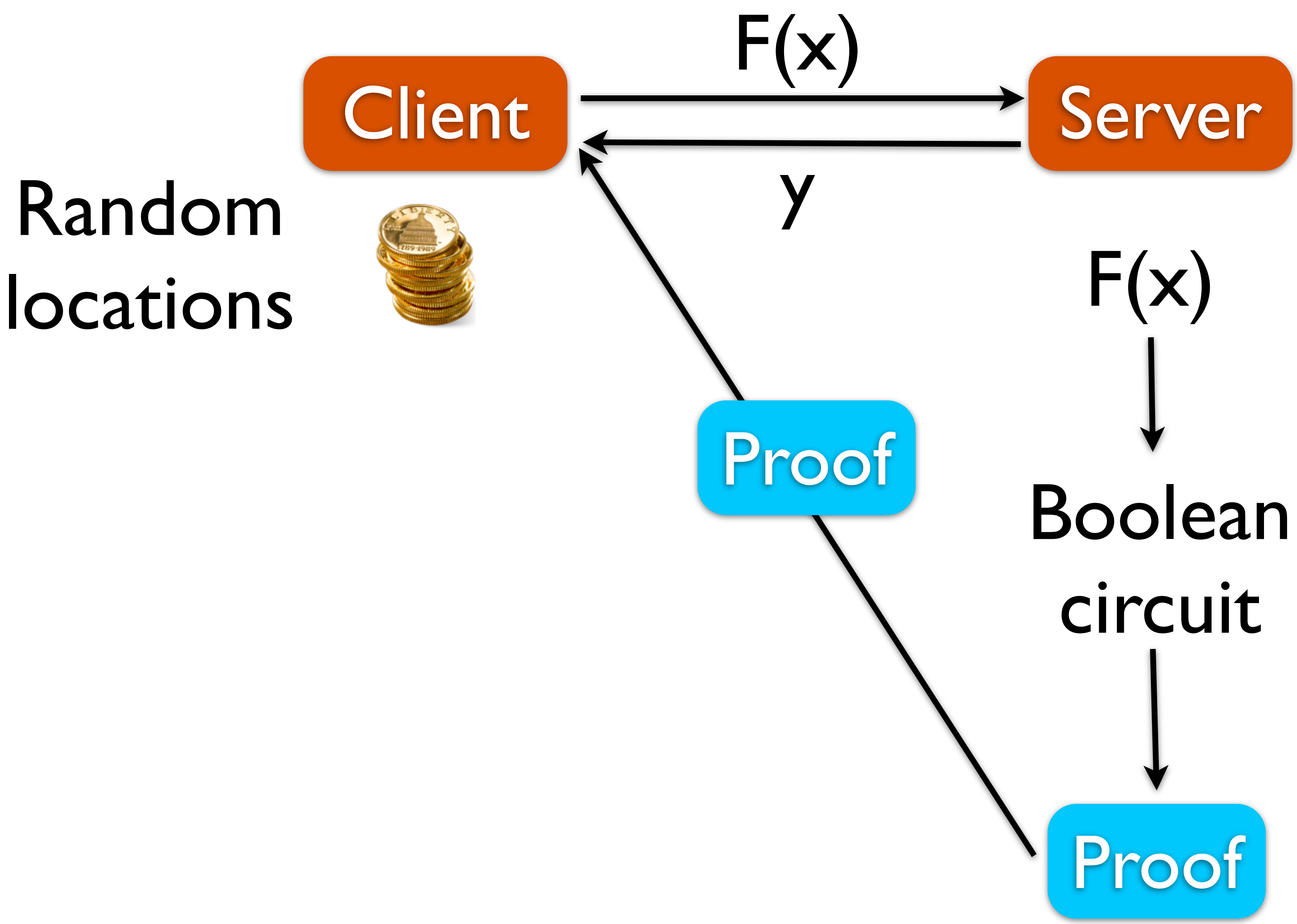

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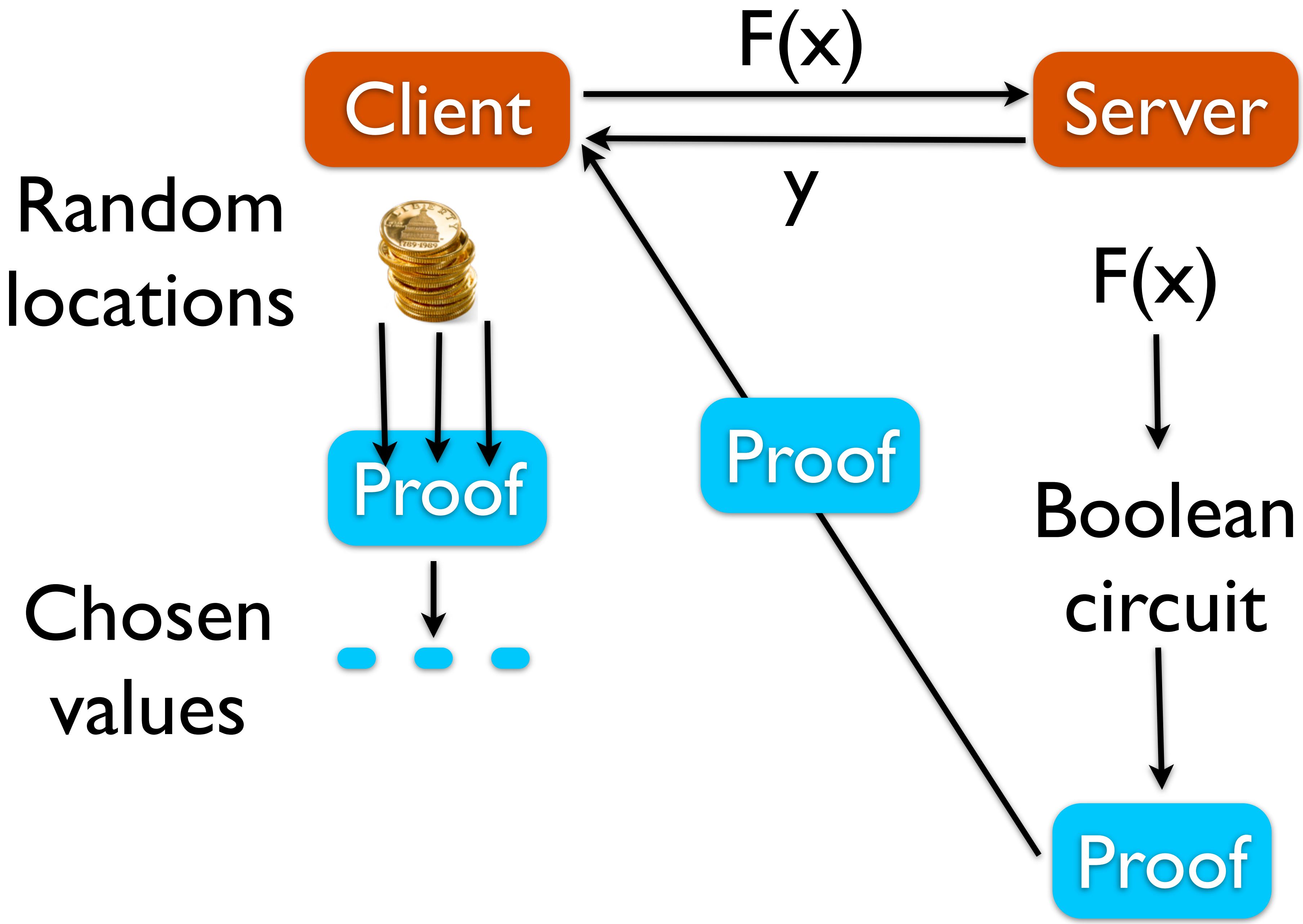

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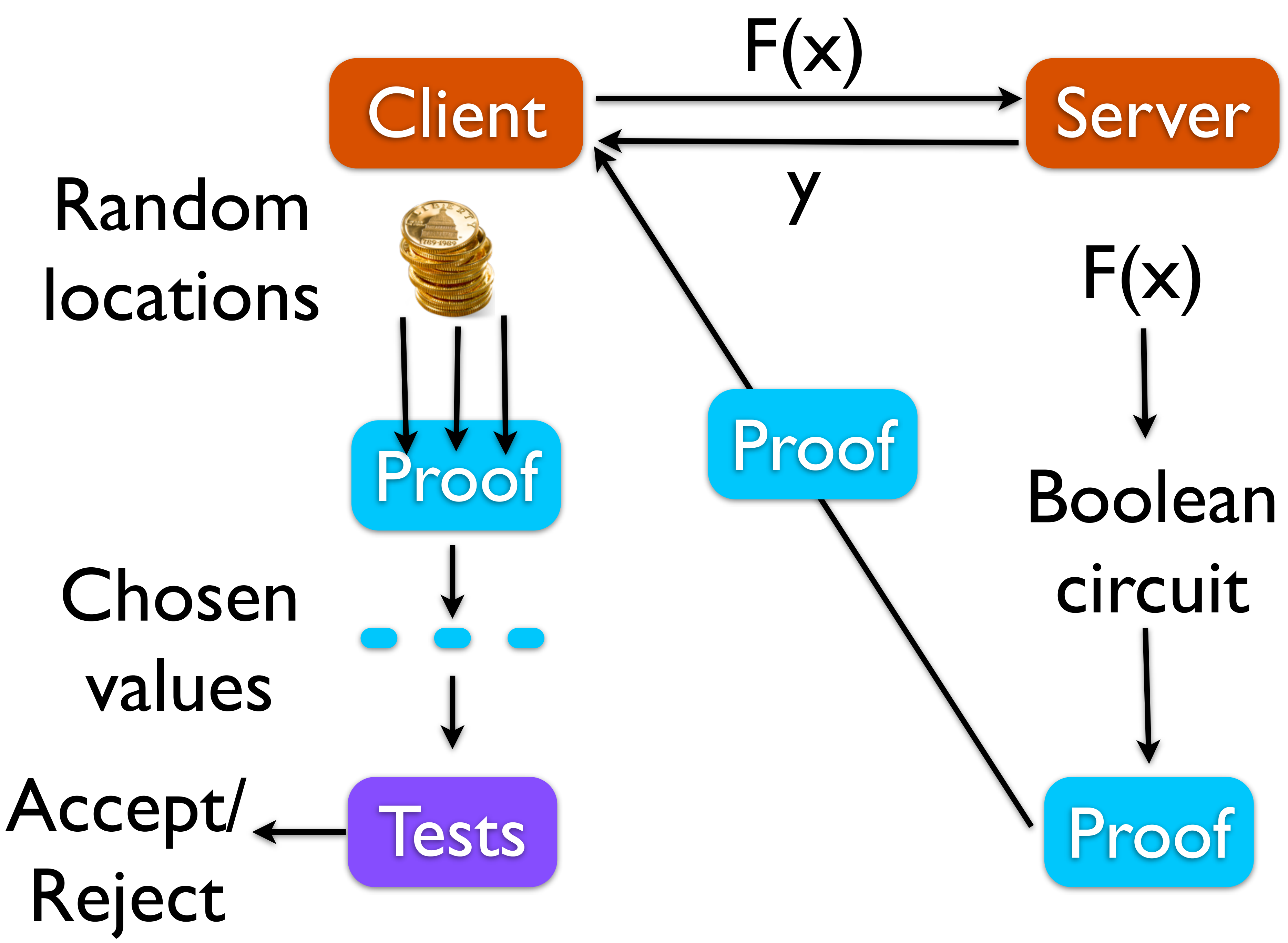

Our attempt to make PCPs practical

- Build on the work that introduces interaction [Kilian CRYPTO'95, Ishai et al. CC'07]
- Use a higher-level abstraction to represent computations
  - Reduces cost by 8 orders of magnitude
- Apply a divide-and-conquer technique
  - Reduces cost by 2 orders of magnitude

We build on an interactive variant of PCPs

[Ishai et al. CC'07]

- The server proof is a generating function
- The server responds to queries by evaluating the function
- The client binds the server to its function using cryptographic commitment

Can we use a higher-level abstraction?

- Use arithmetic circuits instead of Boolean circuits
- Savings:
  - 8 orders of magnitude at the server
  - 4 orders of magnitude at the client

Can we apply a divide-and-conquer strategy?

- Decompose the computation into parallel pieces
- The client batch-verifies the computation
- Saves two orders of magnitude in costs

Examples that we implemented

- Polynomial evaluation
- Matrix multiplication
- Fast Fourier Transform (FFT)
- Image filtering with convolution matrices

Example savings

For polynomial evaluation with 700 variables

	interactive baseline	post-refinements
Server's work	130,000 years	11.5 hours
Client's work	940 sec	94 msec

(Local execution time: 164 msec)

→ The scheme is near-practical

Summary

- Our refinements reduce costs by over 10 orders of magnitude
- More refinements are required to make the scheme fully practical
- Upshot: PCP-based verified computation can be a systems problem