Advanced Tools from Modern Cryptography

Lecture 0

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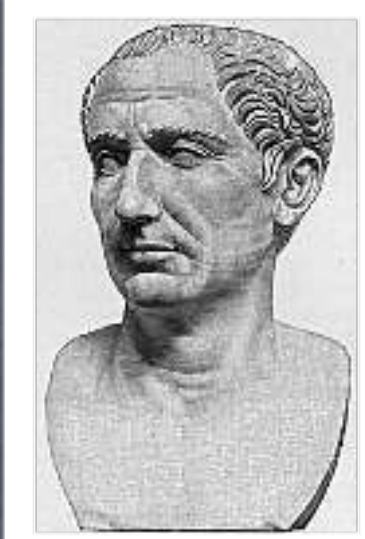
"Old" Cryptography

Scytale (ancient Greece)

Caesar Cipher



100 BC - 44 BC

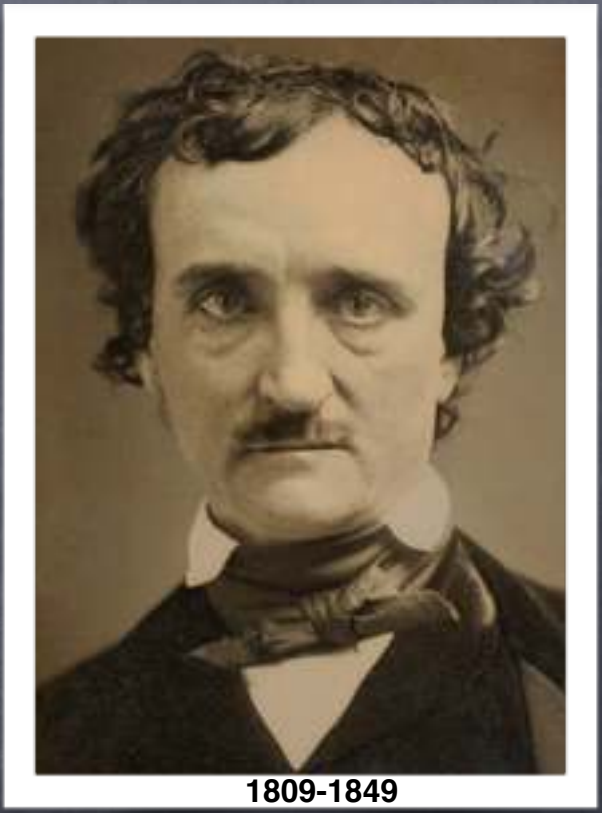
801-873

Cryptanalysis (simple frequency analysis)
of Caesar cipher by Al-Kindi

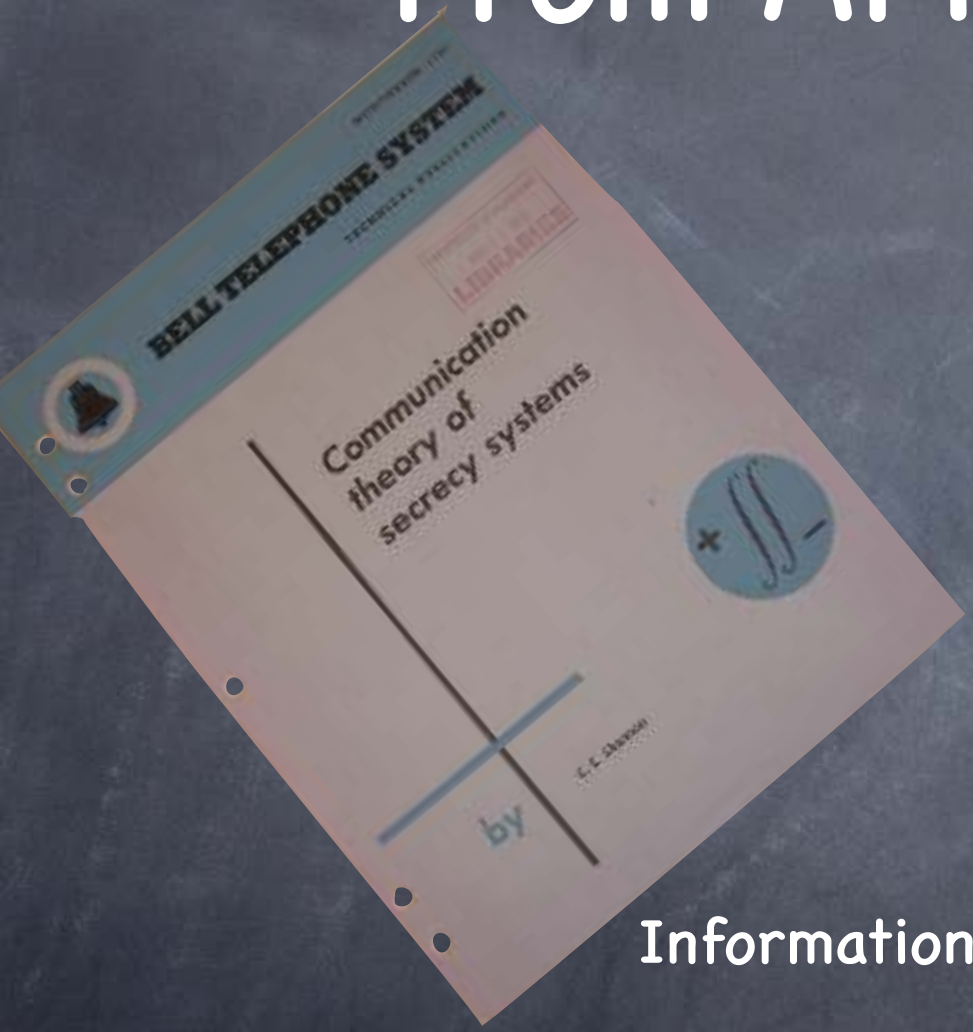
"Old" Cryptography

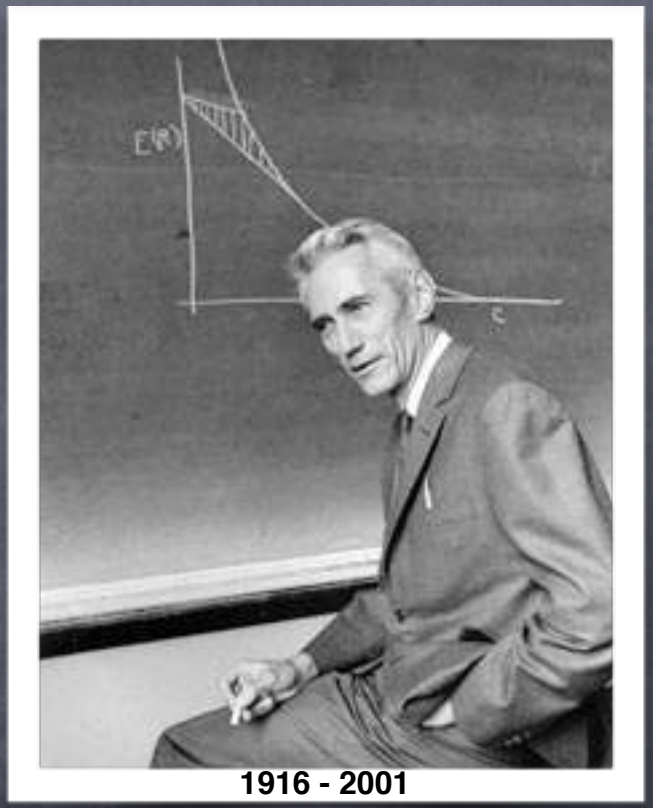
"Human ingenuity cannot concoct a cypher which human ingenuity cannot resolve"

-Edgar Allan Poe



From Art to Science




1916 - 2001

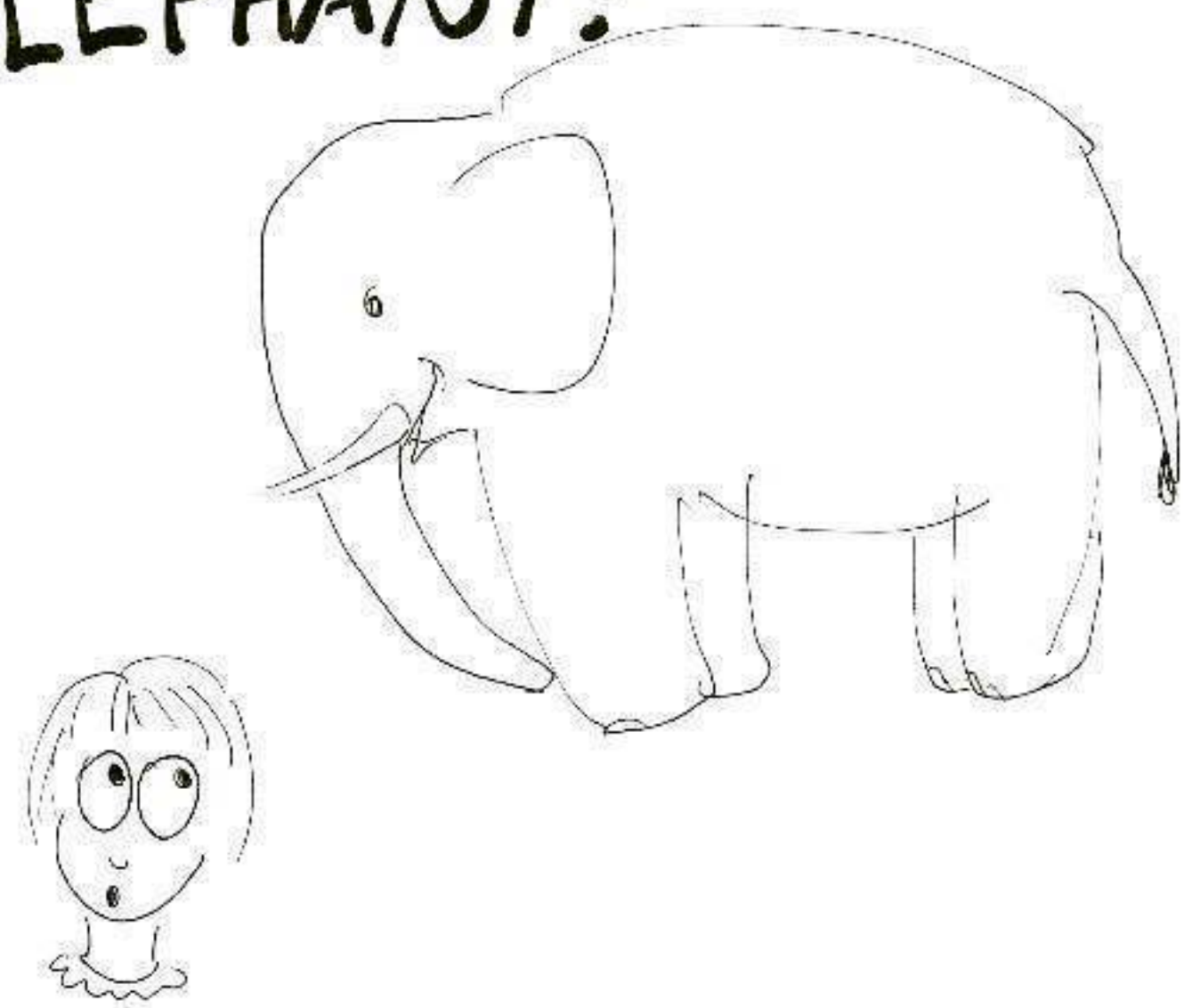
Information can be quantified

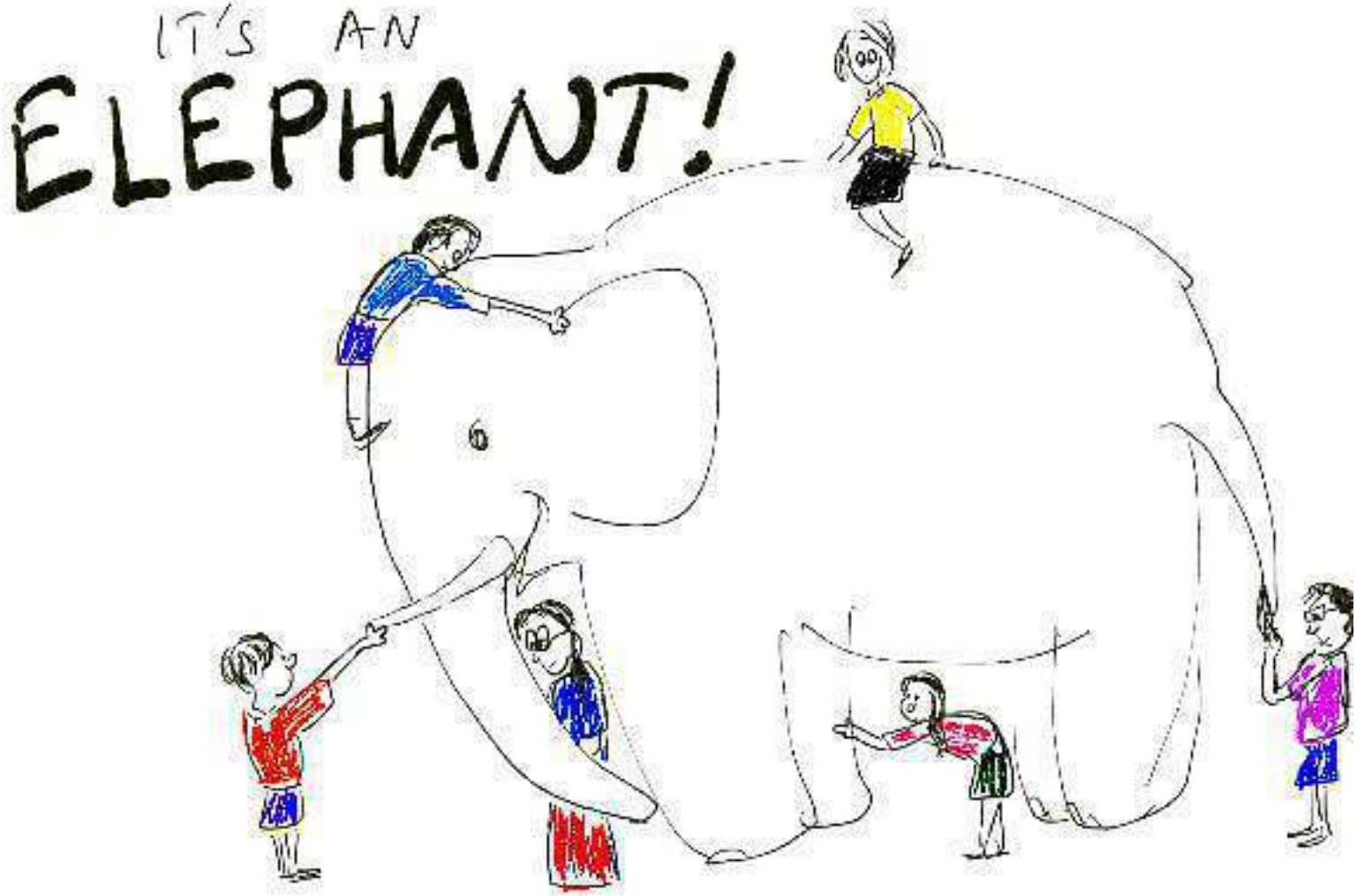
Perfect secrecy: ciphertext has zero information about the message

Key to perfect secrecy: Randomness

What is Modern Cryptography?

IT'S AN
ELEPHANT!

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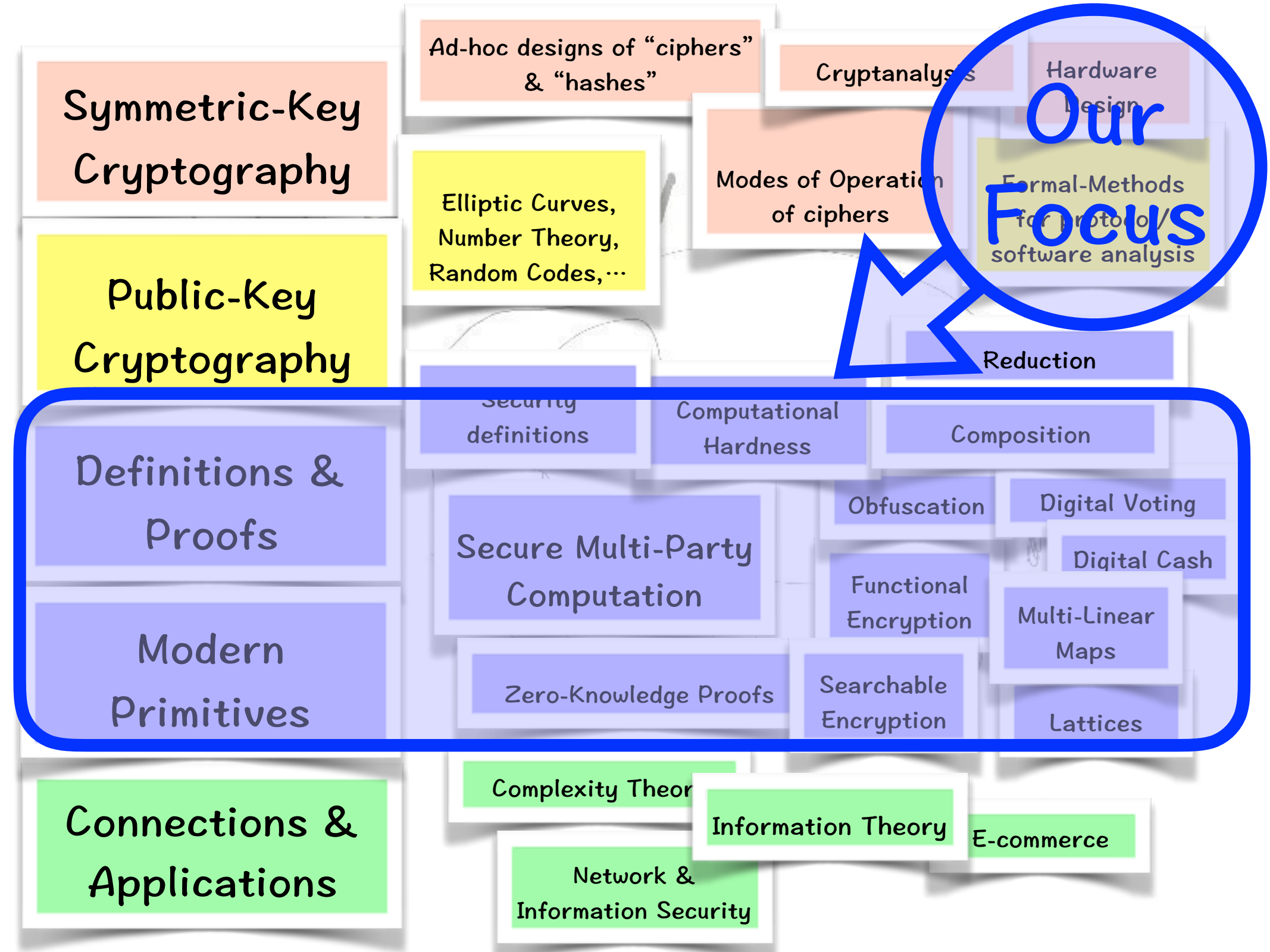

Symmetric-Key Cryptography
Ad-hoc designs of "ciphers" & "hashes"
Cryptanalysis
Hardware Design
Our Focus
Modes of Operation of ciphers
Formal-Methods for protocol/ software analysis
Public-Key Cryptography
Elliptic Curves, Number Theory, Random Codes,…
Reduction
Security definitions
Computational Hardness
Composition
Definitions & Proofs
Obfuscation
Digital Voting
Secure Multi-Party Computation
Digital Cash
Functional Encryption
Multi-Linear Maps
Modern Primitives
Zero-Knowledge Proofs
Searchable Encryption
Lattices
Complexity Theor
Information Theory
E-commerce
Connections & Applications
Network & Information Security

Symmetric-Key Cryptography

Public-Key Cryptography

Definitions & Proofs

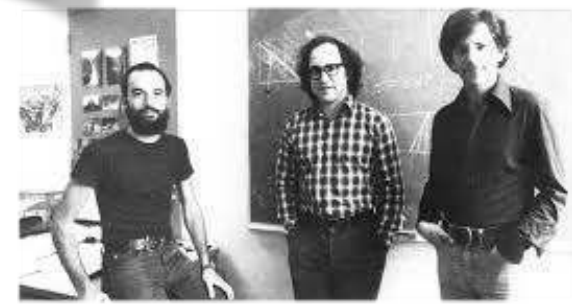
Modern Primitives

Connections & Applications

Claude Shannon

Alan Turing

Merkle, Hellman & Diffie
Turing Award '15



Shamir , Rivest & Adleman
Turing Award '02

Manuel Blum
Turing Award '95

Andrew Yao
Turing Award '00

Goldwasser & Micali
Turing Award '12

Modern Cryptography

- Some tools
  - Secure Multi-Party Computation (MPC)
    - In particular, Zero-Knowledge Proofs
  - Private Information Retrieval (PIR)
  - Fully Homomorphic Encryption (FHE)
  - Functional Encryption (FE)
  - Obfuscation
  - Searchable Encryption
  - Oblivious RAM (ORAM)
  - Leakage-Resilient tools
- Tools for what?

Collaboration

- ... Among mutually distrusting entities
- **Secure Multi-Party Computation**
  - Example: Company A is shopping for parts for its new product from a supplier, Company B.
  - Example: Auctions, where only the winners' payments need to be revealed
  - Example: Govt. agencies collaborating to enforce laws while respecting the privacy of citizens

Securing Cloud Storage

- Private Information Retrieval
  - Don't want the server to see my access pattern
- Searchable Encryption
  - Allow search operations on data stored encrypted on the server (OK to reveal the access pattern)
- Oblivious RAM
  - Allow read and write operations on data stored on the server, and do not reveal access pattern

Computing on Encrypted Data

- Similar goals as achieved by MPC, but with very restricted interaction among parties (and weaker security guarantees)
- **Fully Homomorphic Encryption**: computing server does not see the data; client need not do the computation, but only encryption/decryption
- **Functional Encryption**: keys can be issued to allow computation of specific functions, with the outcome becoming available to the computing party
- **Obfuscation**: "Encrypted" function that can be run on any input (without needing a key)

Connections

- These are also often tools for building other cryptographic tools
  - e.g., ORAM can be used for MPC
  - e.g., MPC can be used for FE
  - e.g., MPC for leakage resilience
- They share some common underlying primitives
  - e.g., Secret-sharing, Randomized Encoding

Definitions

- Important to be precise about what these (complicated) tools actually guarantee
- Even for a simple tool like encryption, easy to misunderstand its guarantees
  - e.g., malleability, circular (in)security, ...
- Strong security definitions are often provably impossible to achieve for many of these tools
  - e.g., (standard) "universally composable" security for

Course Plan

- Quick run-through of basic concepts like indistinguishability and basic tools like pseudorandom functions
- Will start with MPC
- As many other topics as possible, as time permits

Course Logistics

- Grading:
  - Two Quizzes (60%)
  - ≈3 HW assignments (18%)
  - Course project (20%)
  - Attendance (2%)
- "Theory" course: no programming requirement, but your course project could be a programming project
  - We have an MPC programming language now!
- Office hours TBA
- Course webpage: see cse.iitb.ac.in/~mp/teach/