

# Communication & Computation

A need for a new unifying theory

**Madhu Sudan**

Microsoft Research + MIT

# Theory of Communication



- Shannon's architecture for communication over noisy channel



- Yields reliable communication
  - (and storage (= communication across time)).

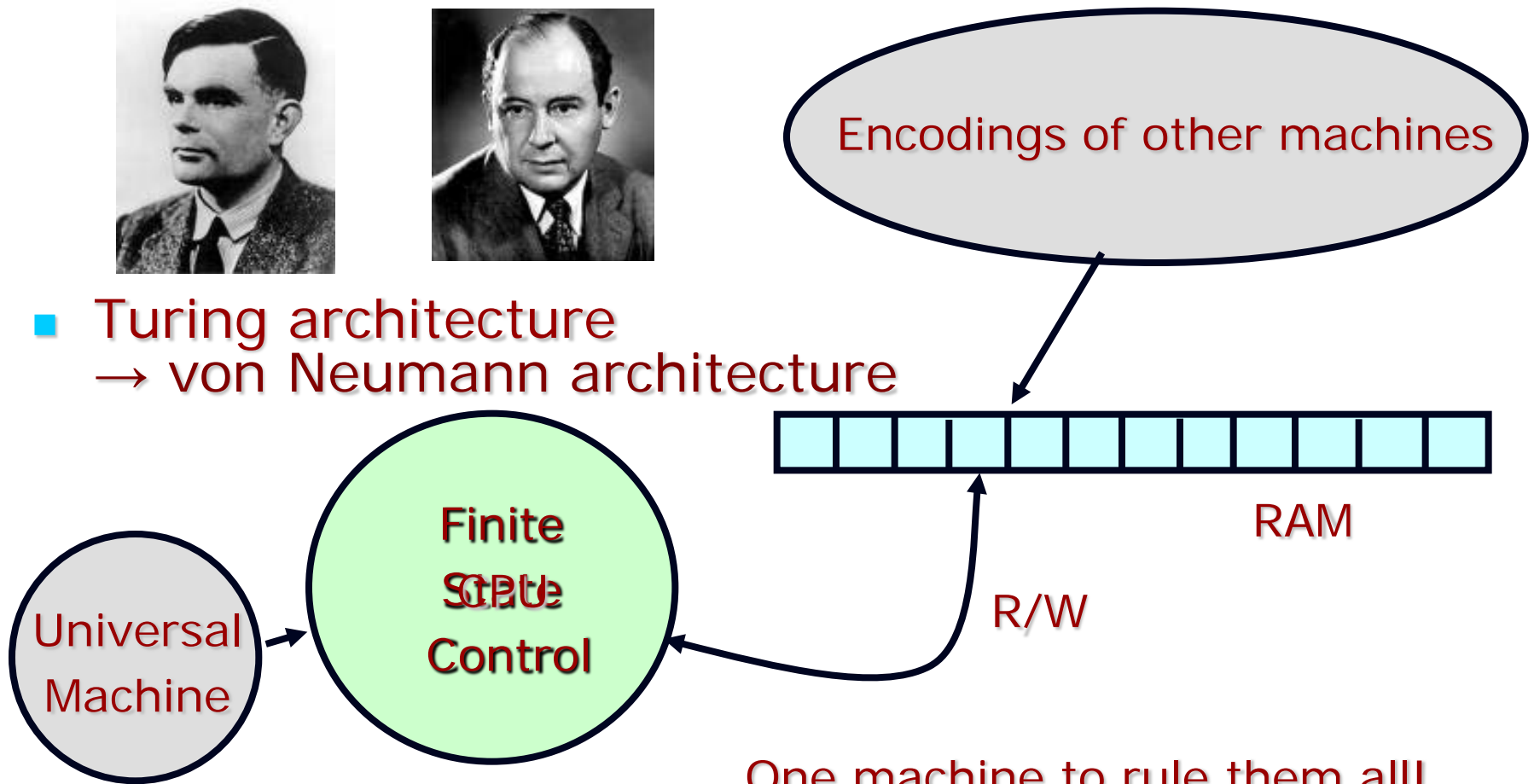
# Encoders & Decoders?

- Mathematically: (arbitrary) functions.
- Physically: Pieces of hardware – to compute certain functions.
- (Mathematical/Physical question):
  - Why should the set of functions required have nice hardware to compute them?

# Theory of Computing






- Turing architecture  
→ von Neumann architecture



# Consequence

- Any ((polynomial time) computable) function does have nice hardware.
- However ...
  - Requires reliable CPU  $\leftrightarrow$  RAM
  - Requires reliable RAM
- Conclusion:
  - Computing needs Communication
  - Communication needs Computing  
(we are extremely lucky to get out of the loop)

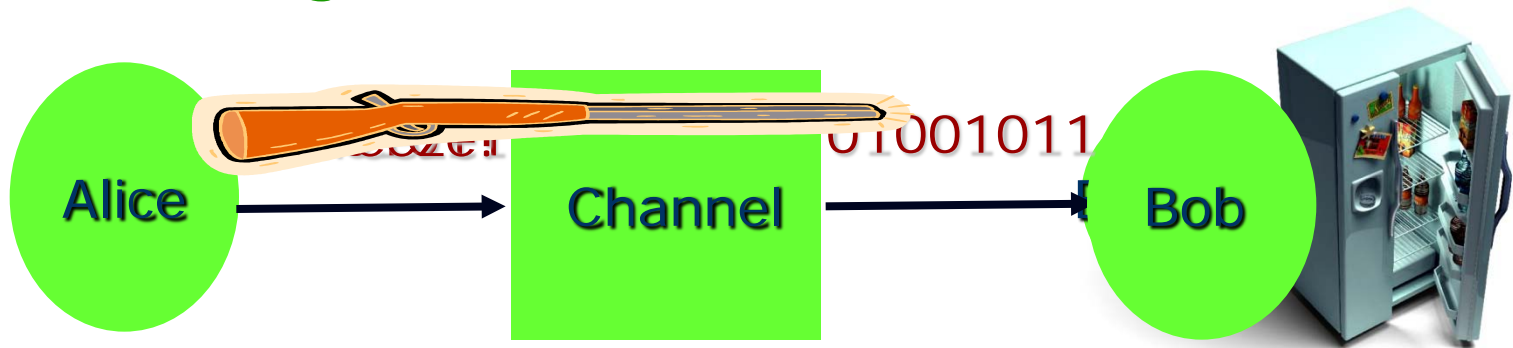
## ~ 70 years since

- Computing and Communication thriving
  - Separate theoretically
  - Unified physically (in gadgets in my pocket).
- My Opinion: Need to unify the theories
  - Why?
    - Need to know the limits of what can be done
    - Need to know what is being done?
      - What are    ?
      - Modern practice has rich mix of computing/communication apps? What is the problem space? What is the solution space?

# Communication: Goals, Semantics

- To make for reliable, useful, communication:
  - Need to formalize: Goals of communication
    - In each usage
      - Why is each player communicating? What is the end effect that it desires?
      - What is each player assuming about others?
      - How will it know if something goes wrong?
  - Communication should preserve meaning:
    - Players allow for, and recover from, misunderstandings at endpoints.

# The Meaning of Bits

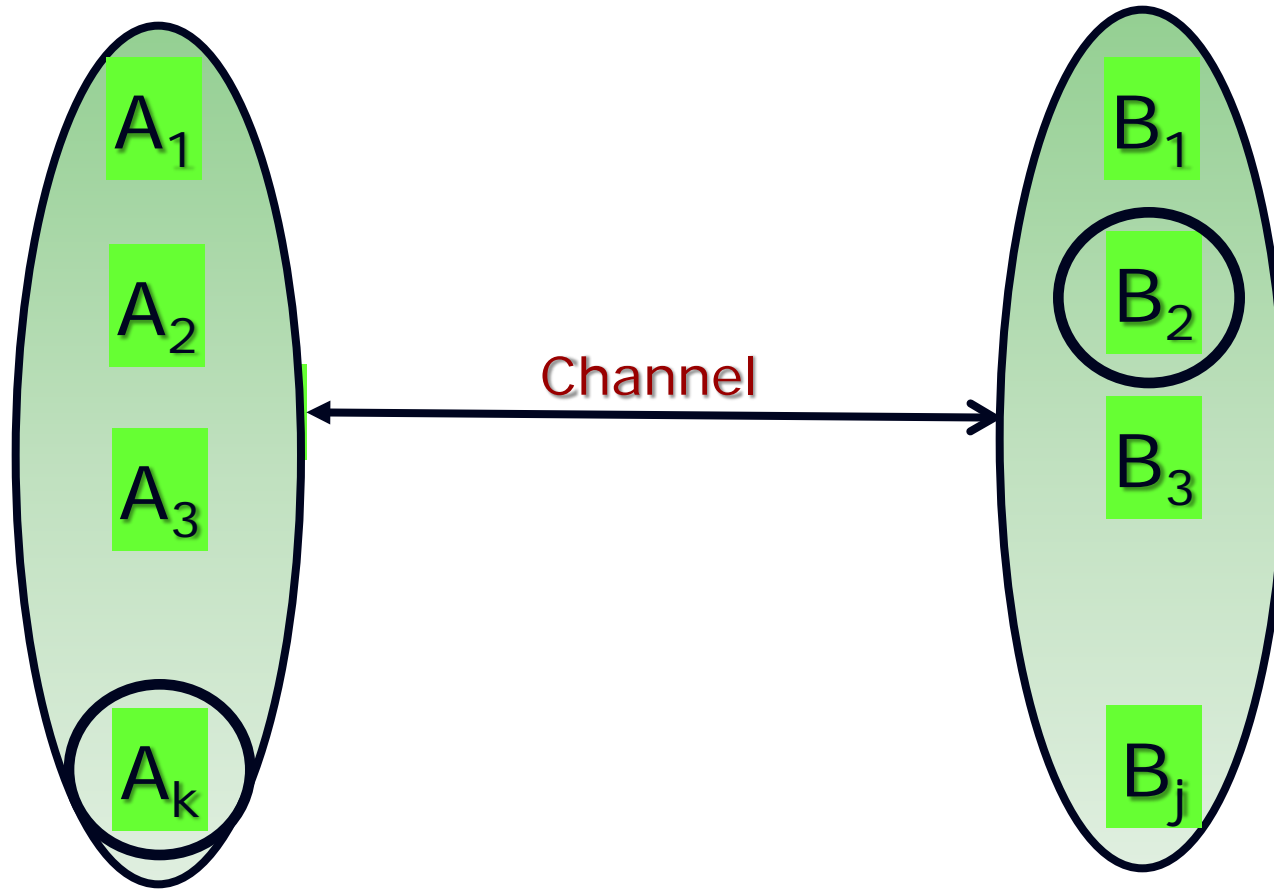


- Why did miscommunication occur?
  - Alice assumed Bob knows colloquial English;
  - But she's actually talking to some Bob' who doesn't.



# Modelling Miscommunication

## Semantic Communication Model



# Our claims

(based on joint works with Juba, Goldreich, Kalai, Khanna)

- Semantic Communication can be achieved with almost full diversity
  - If goals of communication are formally captured and “sensible”; and players are “helpful” [GJS]
  - Communication does offer advantages even in purely informational settings [JS1]
  - Can be attained almost w.l.o. efficiency [JS2]
  - Explains difference between engineered and natural communication (e.g., ambiguity in natural language) [JKKS]

# Communicating Knowledge [JS1]

- Knowledge (X) = Subset of Information (X)
  - Useful/Useable
  - Not known without X.  
[Goldwasser, Micali, Rackoff ~86]
- Knowledge  $\leq$  Information (usually  $\ll$ )
- In all practical settings: Suffices to communicate Knowledge.
  - Can be communicated with misunderstanding.
  - Can be used to overcome misunderstanding.
  - Because it is useful!

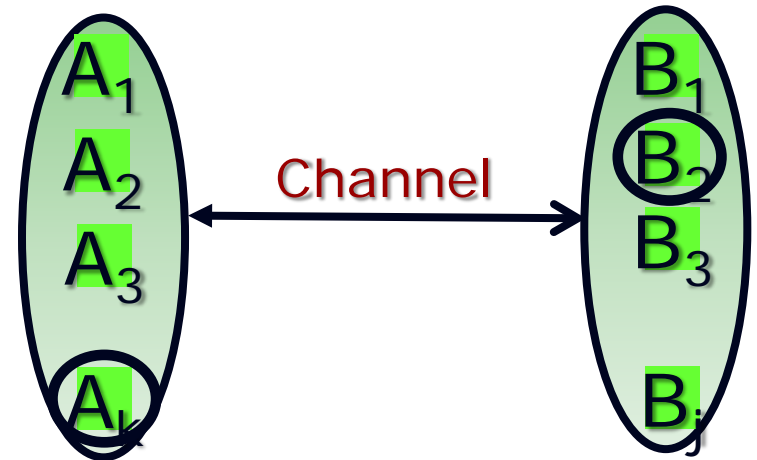
# Going Forward

- Need to build robust theory of “why (anyone/everyone) communicate(s)”

- Combine with Semantics

- Needed to improve

- Improve Reliability
- Reduce Vulnerability
- Increase efficiency
- Safely transfer all information to digital form.



# References

- [JS1]: Juba and Sudan, STOC 2008.
- [GJS]: Goldreich, Juba, and Sudan, ECCV 2009
- [JS2]: Juba and Sudan, ICS 2011 (to appear)
- [JKKS]: Juba, Kalai, Khanna, Sudan, ICS 2011 (to appear)