Universal Semantic Communication

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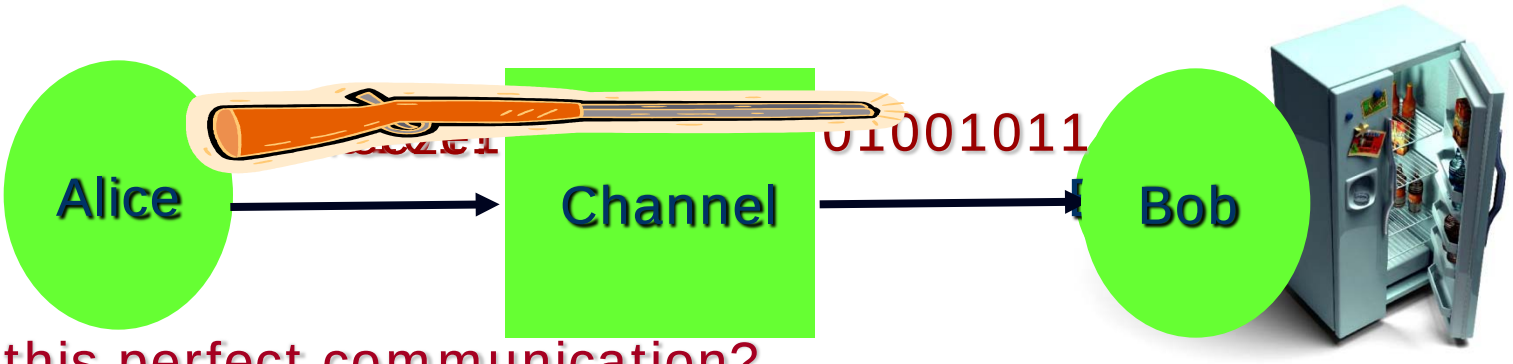
The Meaning of Bits



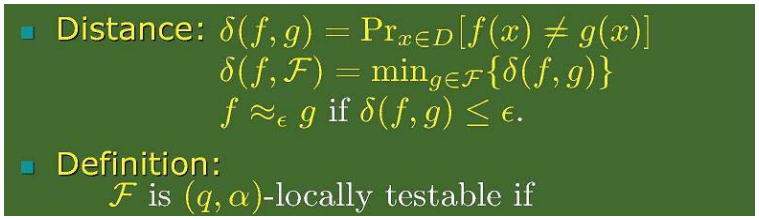
- Is this perfect communication?

- What if Alice is trying to send instructions?
  - Aka, an algorithm
  - Does Bob understand the correct algorithm?
  - What if Alice and Bob speak in different (programming) languages?

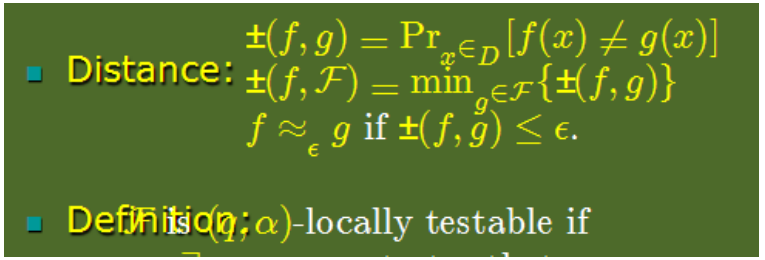
Part I: Context/Motivation

What? Why?

- Example 1: I have a presentation that used to work well on my last laptop.



- I transferred the file to my new laptop and it looks like this.



- ... but the bits are intact!

What? Why?

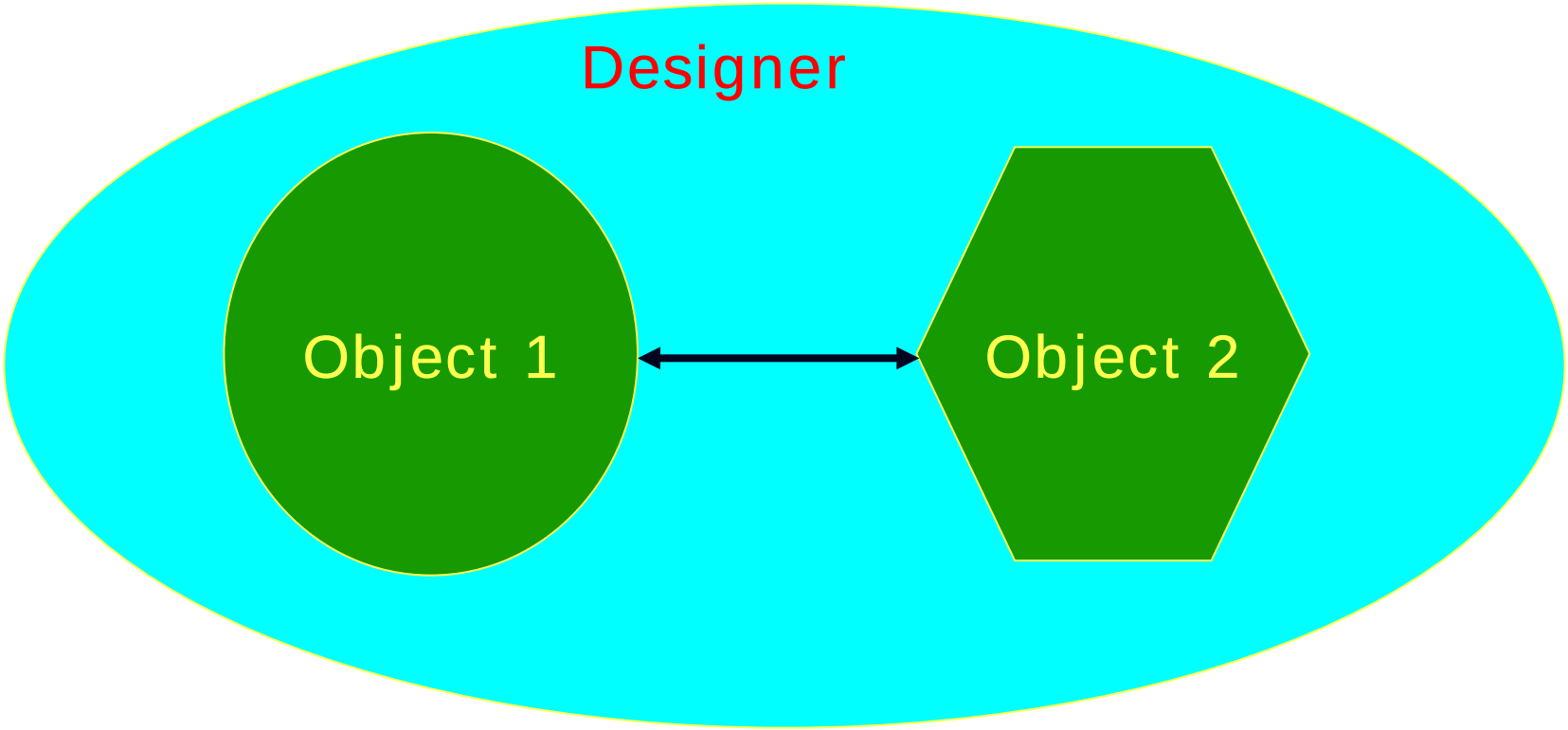
- Example 2: I would like to print some document on some printer.
  - You can do it.
  - I have same permissions as you.
  - But I don't have the printer installed.

- I have the information … I don't know how to translate to printer's language.

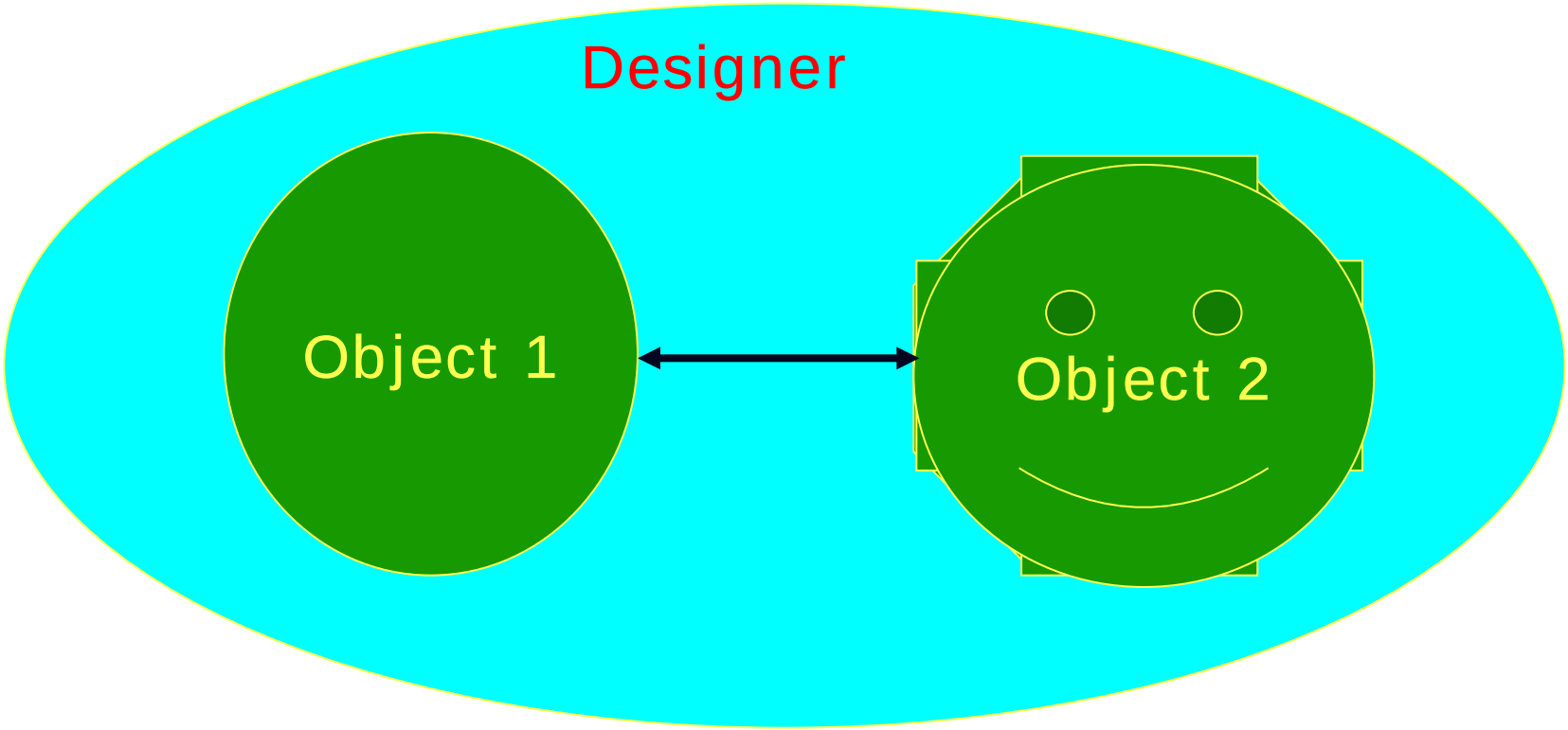
Motivation: Better Computing

- Computers are constantly communicating.
- Networked computers use common languages:
  - Interaction between computers (getting your computer onto internet).
  - Interaction between pieces of software.
  - Interaction between software, data and devices.
- Getting two computing environments to “talk” to each other is getting problematic:
  - time consuming, unreliable, insecure.
- Can we communicate more like humans do?

Classical Paradigm for interaction



New paradigm



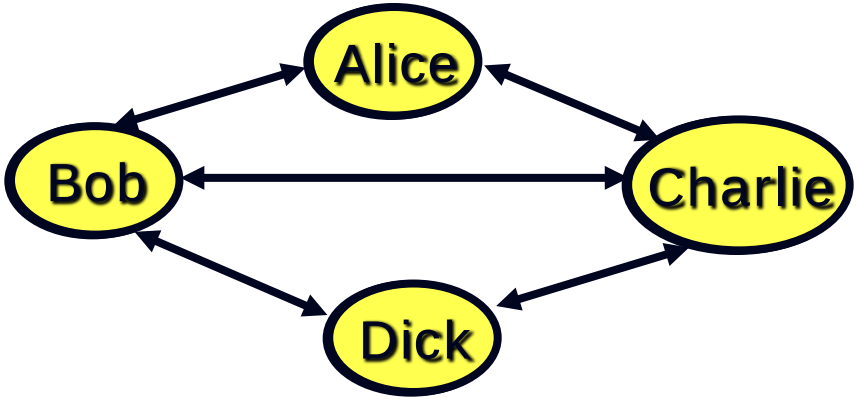
Bits vs. their meaning

- Say, Alice and Bob know different programming languages. Alice wishes to send an algorithm A to Bob.
  - A = sequence of bits … (relative to prog. language)
- Bad News: Can't be done
  - For every Bob, there exist algorithms A and A', and Alices, Alice and Alice', such that Alice sending A is indistinguishable (to Bob) from Alice' sending A'
- Good News: Need not be done.
  - From Bob's perspective, if A and A' are indistinguishable, then they are equally useful to him.
- What should be communicated? Why?

Aside: Why communicate?

- Classical "Theory of Computing"

- Issues: Time/Space on DFA? Turing machines?
- Modern theory:



- Issues: Reliability, Security, Privacy, Agreement?
- If communication is so problematic, then why not "Not do it"?

Motivations for Communication

- Communicating is painful. There must be some compensating gain.
- What is Bob's Goal?
  - "Control": Wants to alter the state of the environment.
  - "Intellectual": Wants to glean knowledge (about universe/environment).
- Claim: By studying the goals, can enable Bob to overcome linguistic differences (and achieve goal).

Part II: Computational Motivation

Computational Goal for Bob

- Why does Bob want to learn algorithm?
  - Presumably to compute some function f
    (A is expected to compute this function.)
  - Lets focus on the function f.

- Setting:
  - Bob is prob. poly time bounded.
  - Alice is computationally unbounded, does not speak same language as Bob, but is “helpful”.
  - What kind of functions f?
    - E.g., uncomputable, PSPACE, NP, P?

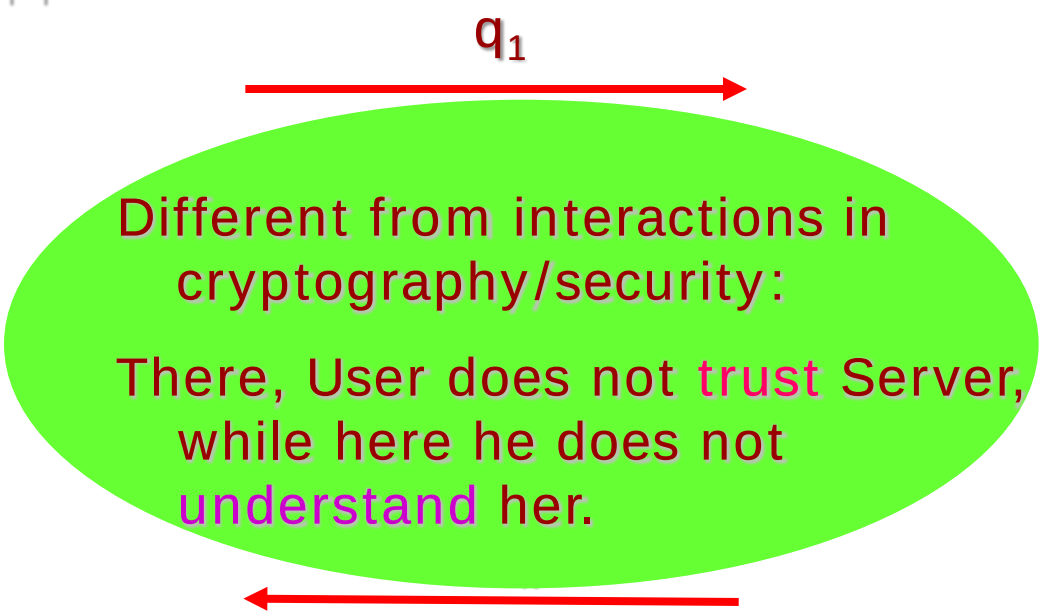
Setup

~~Bob~~ User

~~Alice~~ Server

f(x) = 0/1?

R ← $$$



Computes $P(x,R,a_1,\ldots,a_k)$

Hopefully $P(x,\ldots) = f(x)$!

Intelligence & Cooperation?

- For User to have a non-trivial interaction, Server must be:
  - Intelligent: Capable of computing f(x).
  - Cooperative: Must communicate this to User.
- Formally:
  - Server S is helpful (for f) if

    $\exists$ some (other) user U' s.t.

    $\forall$ x, starting states σ of the server

    (U'(x) $\leftrightarrow$ S(σ)) outputs f(x)

Successful universal communication

- Universality: Universal User U should be able to talk to any (every) helpful server S to compute f.

- Formally:
  - U is f-universal, if

    $\forall$ helpful S, $\forall\ \sigma$, $\forall$ x

    $(U(x) \leftrightarrow S(\sigma)) = f(x)$ (w.h.p.)

- What happens if S is not helpful?
  - Paranoid view $\Rightarrow$ output "f(x)" or "?"
  - Benign view $\Rightarrow$ Don't care (everyone is helpful)

Main Theorems [Juba & S. '08]

- If f is PSPACE-complete, then there exists a f-universal user who runs in probabilistic polynomial time.
  - Extends to checkable problems
    - (NP ∩ co-NP, breaking cryptosystems)
    - S not helpful ⇒ output is safe

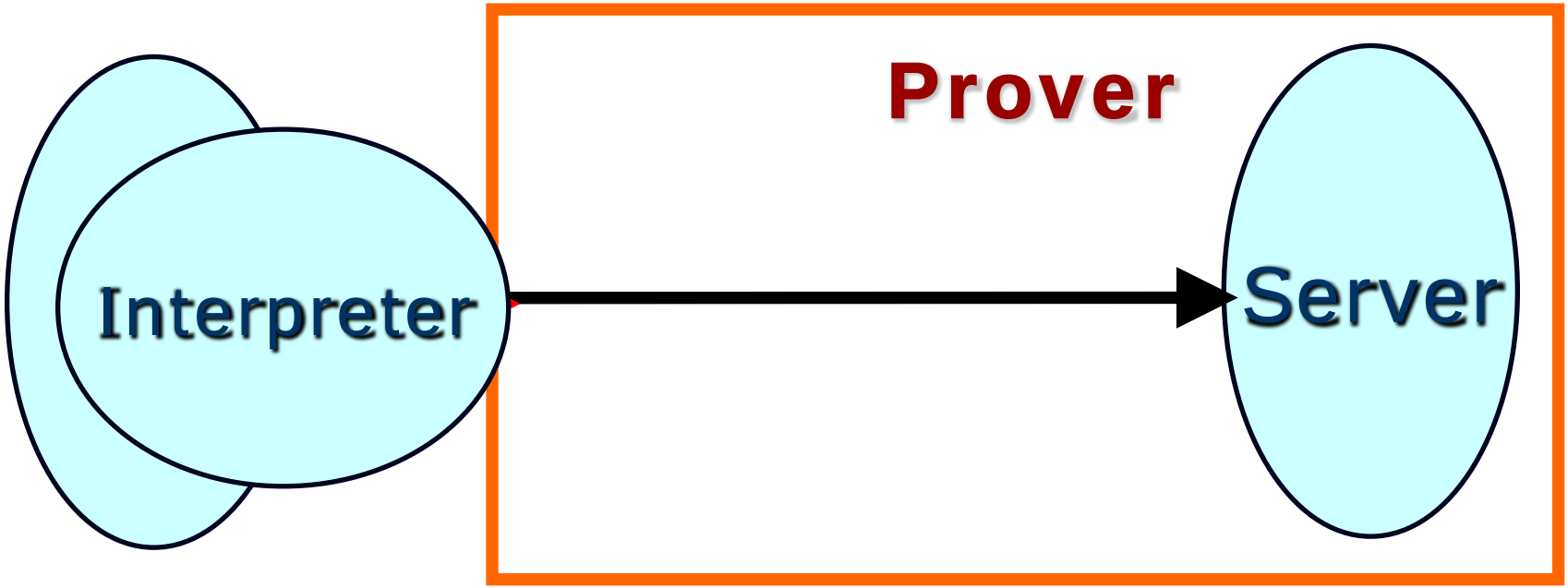
- Conversely, if there exists a f-universal user, then f is PSPACE-computable.
  - Scope of computation by communication is limited by misunderstanding (alone).

Implications

- No universal communication protocol ☹
  - If there were, should have been able to solve every problem (not just (PSPACE) computable ones).
- But there is gain in communication:
  - Can solve more complex problems than on one's own, but not every such problem.
- Resolving misunderstanding? Learning Language?
  - Formally No! No such guarantee.
  - Functionally Yes! If not, how can user solve such hard problems?

Few words about the proof: Positive result

- Positive result: Enumeration + Interactive Proofs
- Guess: Interpreter; $b \in \{0,1\}$ (value of $f(x)$)



- Proof works $\Rightarrow f(x) = b$.
- If it doesn't $\Rightarrow$ {Interpreter or b} incorrect.

Proof of Negative Result

- L not in PSPACE ⇒ User makes mistakes.
  - Suppose Server answers every question so as to minimize the conversation length.
    - (Reasonable effect of misunderstanding).
  - Conversation comes to end quickly.
  - User has to decide.
  - Conversation + Decision simulatable in PSPACE (since Server's strategy can be computed in PSPACE).
  - f is not PSPACE-computable ⇒ User wrong.
  - Warning: Only leads to finitely many mistakes.

Principal Criticisms

- Solution is no good.
  - Enumerating interpreters is too slow.
    - Approach distinguishes **right**/**wrong**; does not solve search problem.
    - Search problem needs new definitions to allow better efficiency.
    - Can find better definitions [Juba+S, ICS'11]
- Problem is not the right one.
  - Computation is not the goal of communication. Who wants to talk to a PSPACE-complete server?

Part III: Generic Goals

Generic Communication [Goldreich, J., S.]

- Still has goals. Goals more diverse.
  - Should be studied; defined formally.

- Major types:
  - Control, e.g.
    - Laptop wants to print on printer.
    - Buy something on Amazon.
  - Sensing/Informational:
    - Computing some (hard) function.
    - Learning/Teaching.
    - Coming to this talk.
  - Mix of the two.

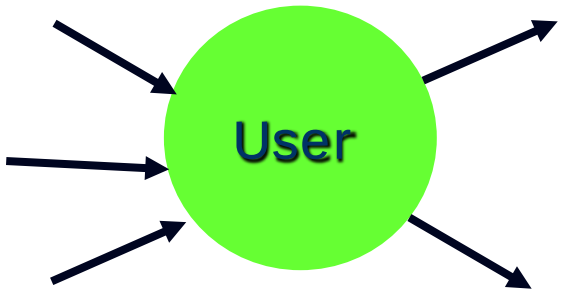
Universal Semantics in Generic Setting?

- Can we still achieve goal without knowing common language?
  - Seems feasible …
    - If user can detect whether goal is being achieved (or progress is being made).
  - Just need to define
    - Sensing Progress?
    - Helpful + Universal?
    - …
    - Goal?
    - User?

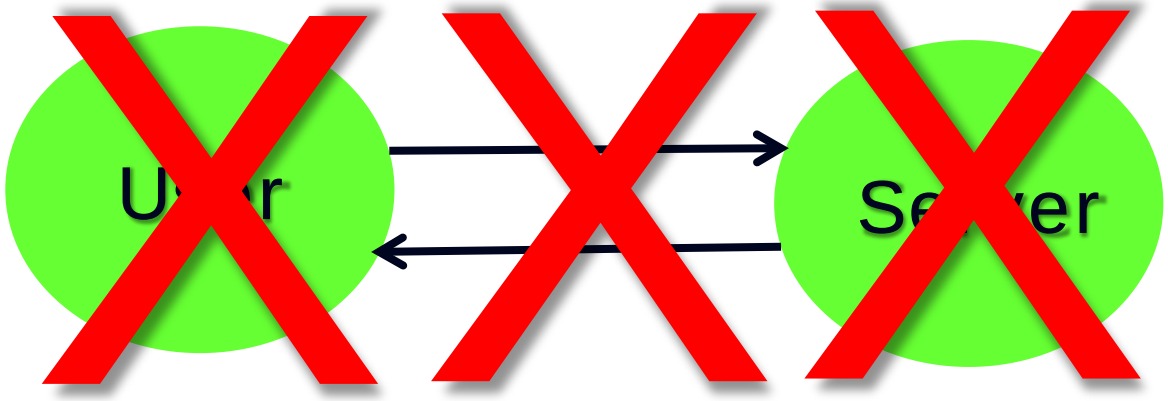
Modelling User / Interacting agents

- (standard AI model)

- User has state and input/output wires.
  - Defined by the map from current state and input signals to new state and output signals.



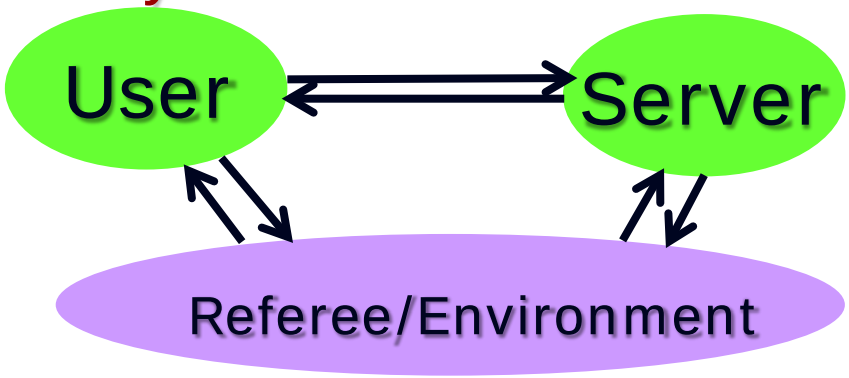
Generic Goal?



- Goal = function of ?
  - User? – But user wishes to change actions to achieve universality!
  - Server? – But server also may change behaviour to be helpful!
  - Transcript of interaction? – How do we account for the many different languages?

Generic Goals

- Key Idea: Introduce 3rd entity: Referee
  - Poses tasks to user.
  - Judges success.



- Generic Goal specified by
  - Referee (just another agent)
  - Boolean Function determining if the state evolution of the referee reflects successful achievement of goal.
  - Class of users/servers.
- Results generalize, assuming "sensing"

Language Learning

- Meaning = end effect of communication.
  - [Dewey 1920s, Wittgenstein 1950s]

- What would make learning more efficient?
  - What assumptions about “language”?
  - How to do encapsulate it as “class” restrictions on users/servers.
  - What learning procedures are efficient?

- Time to get back to meaningful conversation!

Part IV: Some recent works

Efficient Learning & Compatible Beliefs

- Generically:
  - Efficient learning of server not possible.
  - E.g., Password protected server.
- However, if:
  - Server is “broad-minded”
  - User & Server’s beliefs about each other are “compatible”
  - Then efficient learning is possible.
- [Juba+S., ICS ‘11]:
  - Provide definitions of broad-minded, compatible, prove efficiency.

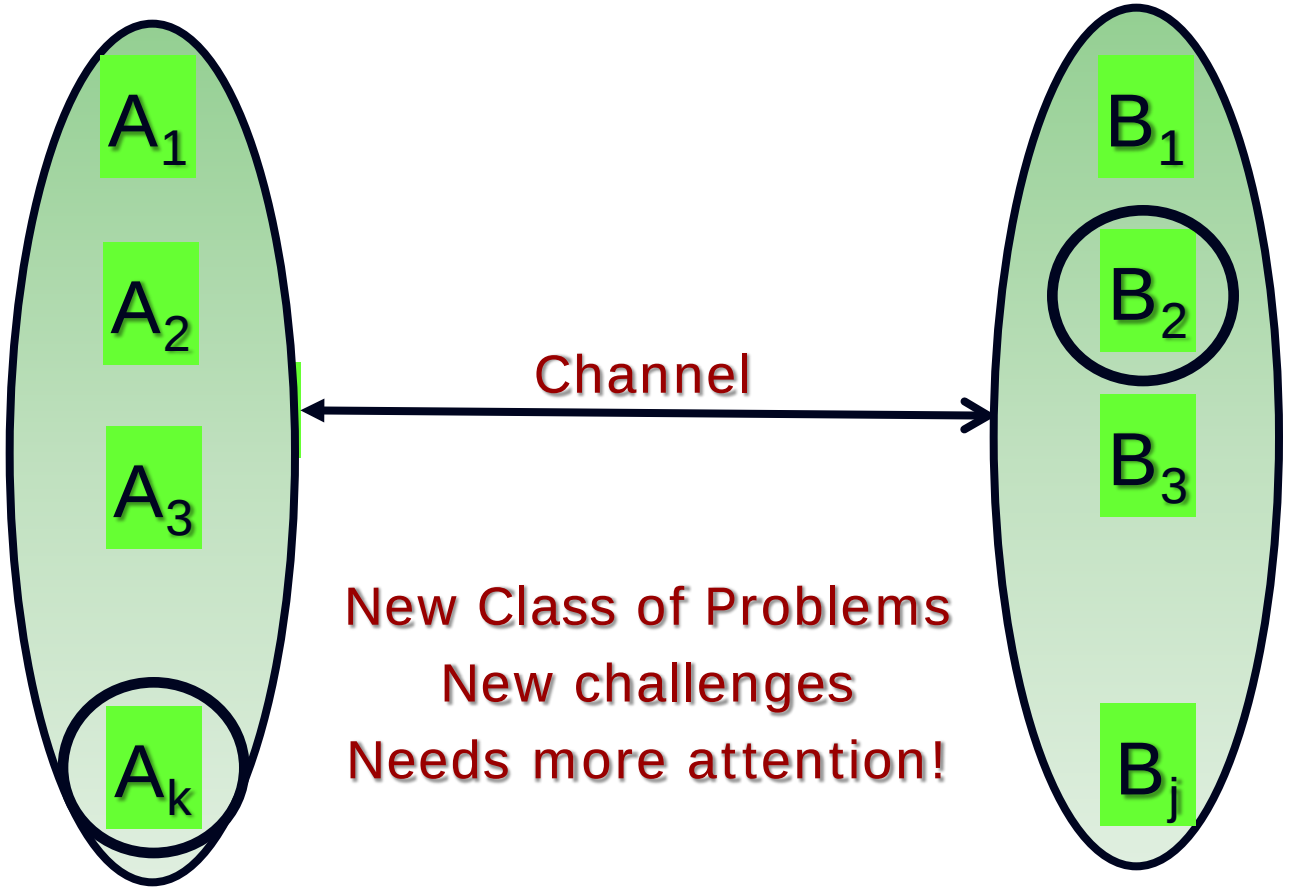
Compression in natural settings

- Human-Human communication:
  - Robust, ambiguous, redundant.

- Explored in [Juba,Kalai,Khanna,S. ICS '11]
  - Thesis: Reason is diversity of audiences/their priors.
  - Leads to compression for "uncertain" priors.
  - Reveals same phenomena:
    - Novel redundancy (increases with uncertainty), still ambiguous, but robust.

Conclusion: A new model

Semantic Communication Model



References

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- Juba, Kalai, Khanna & S.
  - ICS '11: http://people.csail.mit.edu/madhu/papers/ambiguity.pdf

Thank You!