Semantic Goal-Oriented Communication

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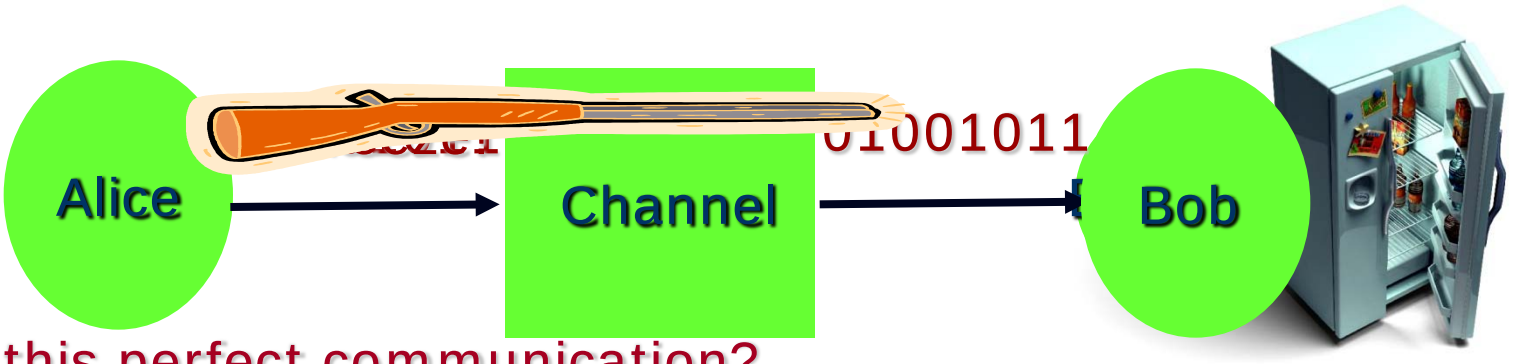
Disclaimers

- Work in progress (for ever) …
- Feedback welcome.
- Interruptions welcome during the talk.
- … Alas, no algebra ☹

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?

Miscommunication (in practice)

- Exchanging (powerpoint) slides.
  - Don't render identically on different laptops.
- Printing on new printer.
  - User needs to "learn" the new printer, even though printer is quite "intelligent".
- Many such examples …
  - In all cases, sending bits is insufficient.
  - Notion of meaning … intuitively clear.
  - But can it be formalized?
    - Specifically? Generically?
    - While conforming to our intuition

Bits vs. their meaning

- Say, User and Server know different programming languages. Server wishes to send an algorithm A to User.
  - A = sequence of bits … (relative to prog. language)

- Bad News: Can't be done
  - For every User, there exist algorithms A and A', and Servers S and S' such that S sending A is indistinguishable (to User) from S' 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?

Part I: Computational Motivation

Computational Goal for Bob

- Why does User want to learn algorithm?
  -

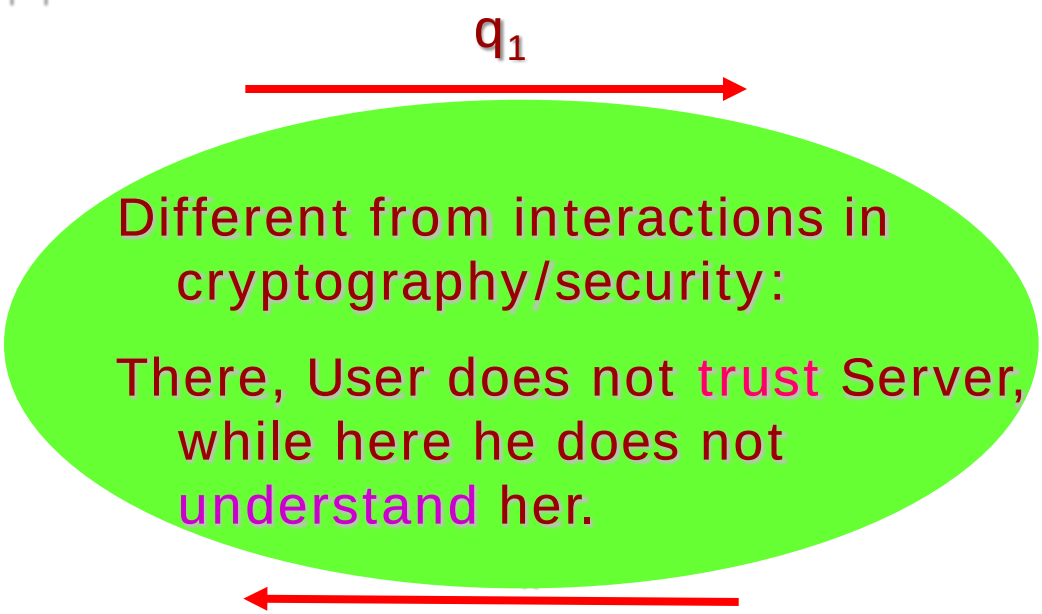
Setup

User

Server

$f(x) = 0/1?$

$R \leftarrow \$\$\$$



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 f-helpful 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) f-helpful server S to compute f.

- Formally:
  - U is f-universal, if

    $\forall$ f-helpful S, $\forall$ σ, $\forall$ 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 ("compIP") 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 (in "compIP")
  - Scope of computation by communication is limited by misunderstanding (alone).

Proofs?

- Positive result:
  - f ∈ PSPACE ⇒ membership is verifiable.
  - User can make hypothesis about what the Server is saying, and use membership proof to be convinced answer is right, or hypothesis is wrong. Enumerate, till hypothesis is right.
- Negative result:
  - In the absence of proofs, sufficiently rich class of users allow arbitrary initial behavior, including erroneous ones.
  - (Only leads to finitely many errors …)

Implications

- Communication is not unboundedly helpful ☹
  - If it 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?

Principal Criticisms

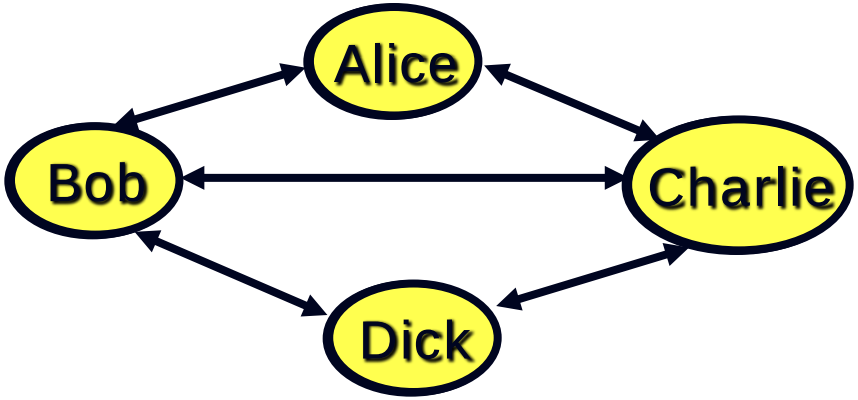
- Solution is no good.
  - Enumerating hypotheses is too slow.
    - Approach distinguishes **right**/**wrong**; does not solve search problem.
    - Search problem needs new definitions to allow better efficiency.
- Problem is not the right one.
  - Computation is not the goal of communication. Who wants to talk to a PSPACE-complete server?

Part II: Generic Goals of Communication

Aside: Communication?

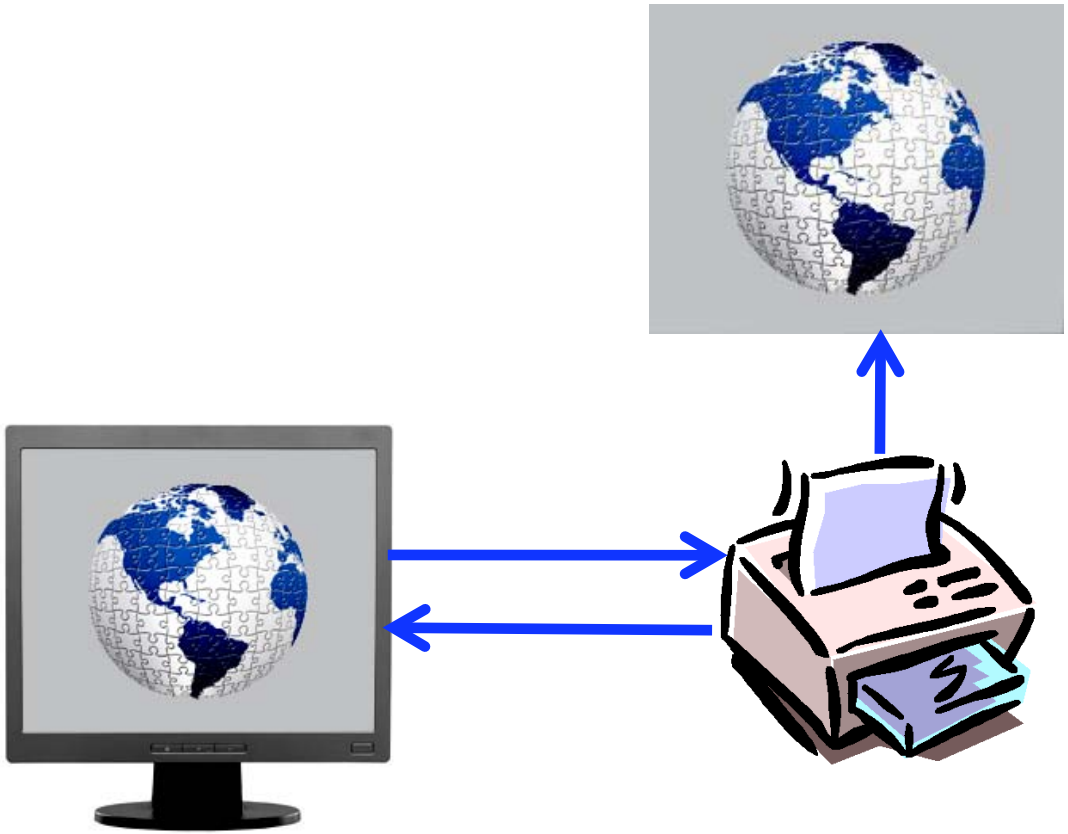
- Classical "Theory of Computing"

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

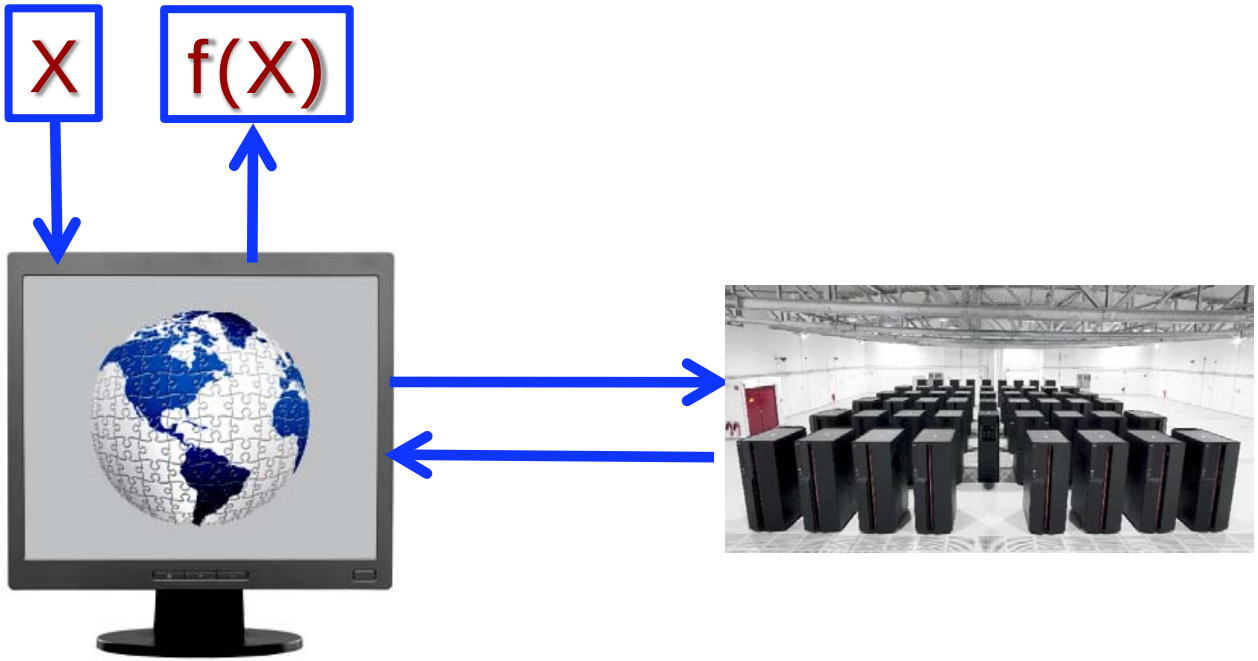


- Issues: Reliability, Security, Privacy, Agreement?
- If communication is so problematic, then why not "Just say NO!"?

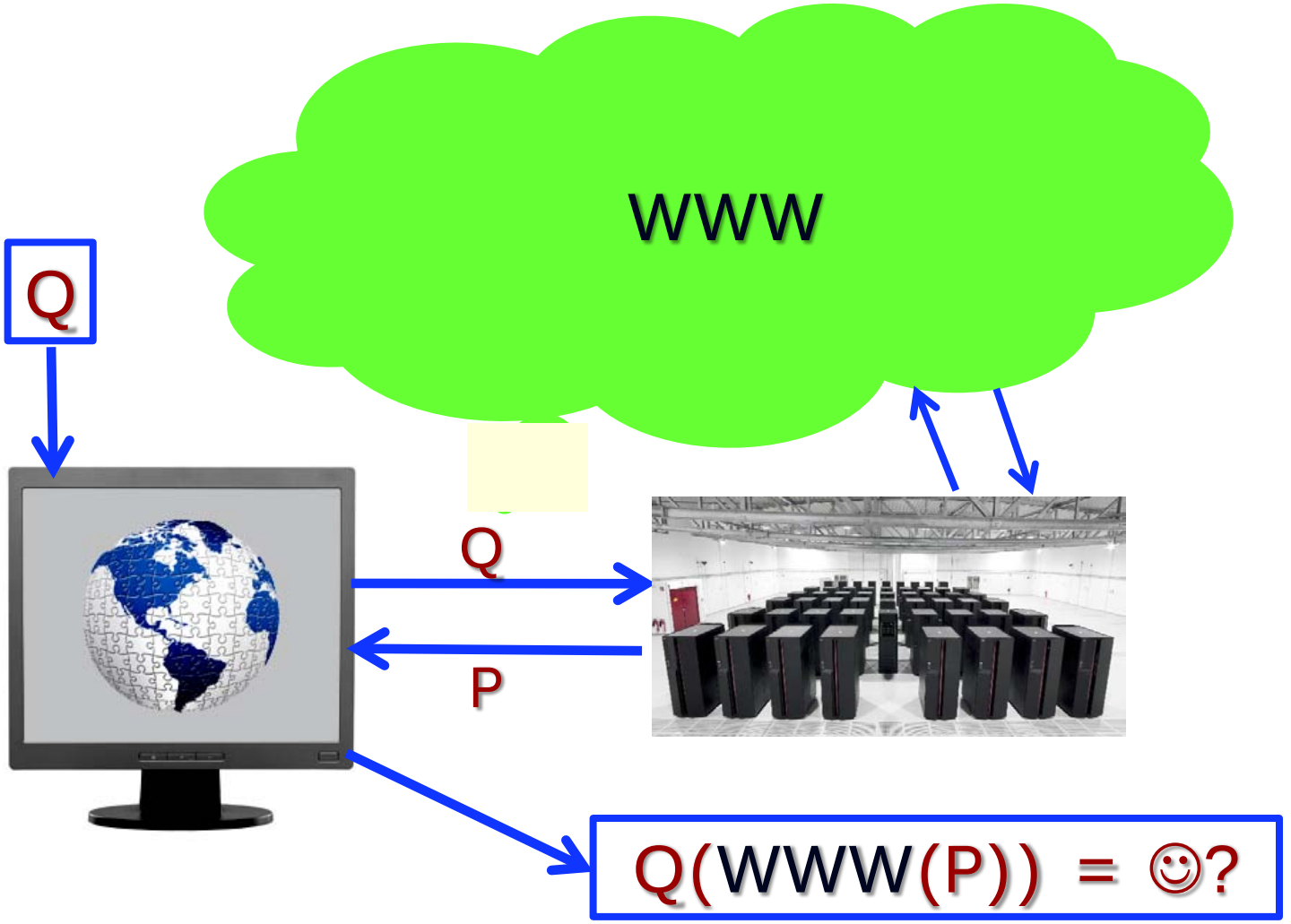
Communication: Example 1 (Printing)



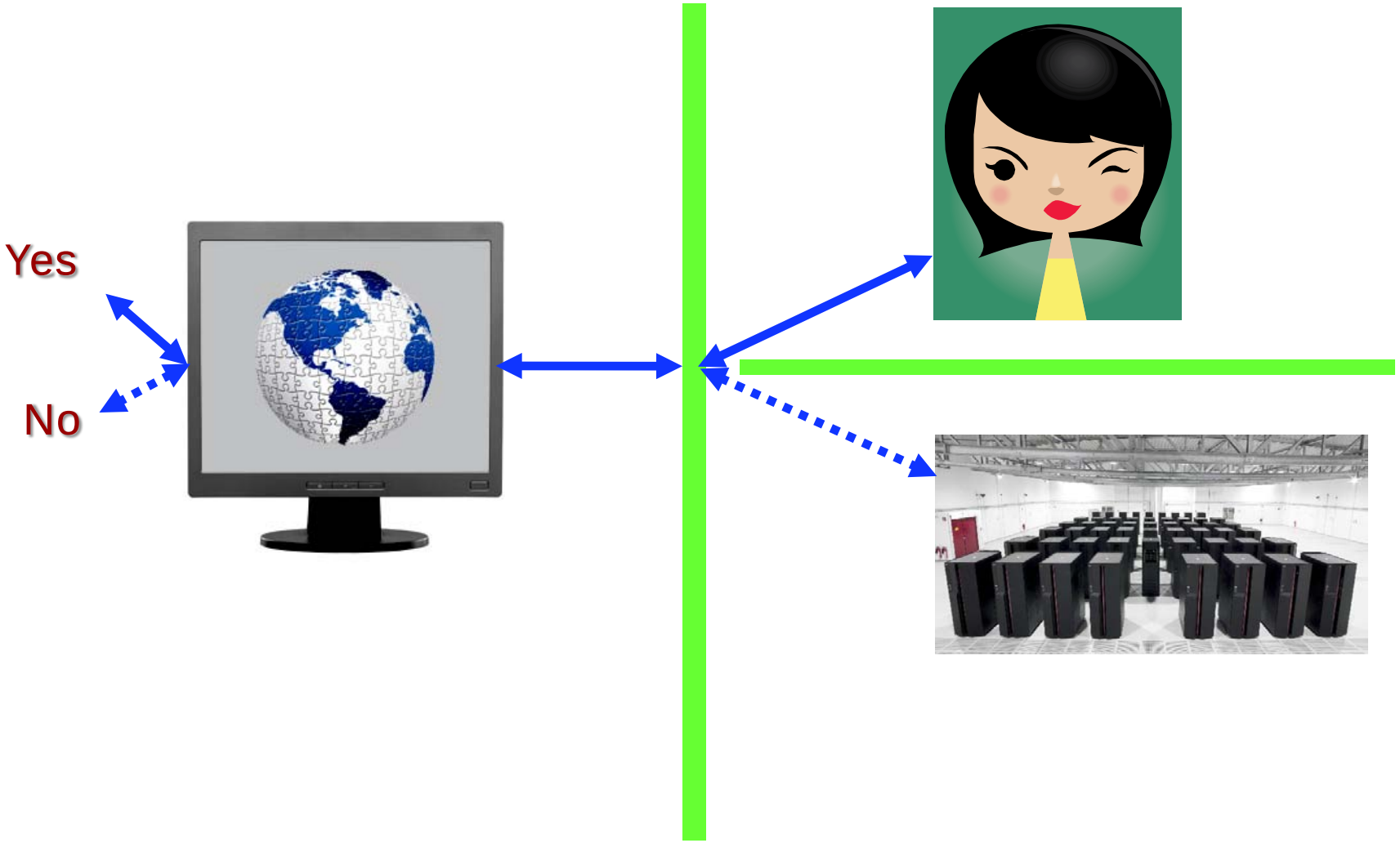
Communication: Ex. 2 (Computation)



Communication: Ex. 3 (Web search)

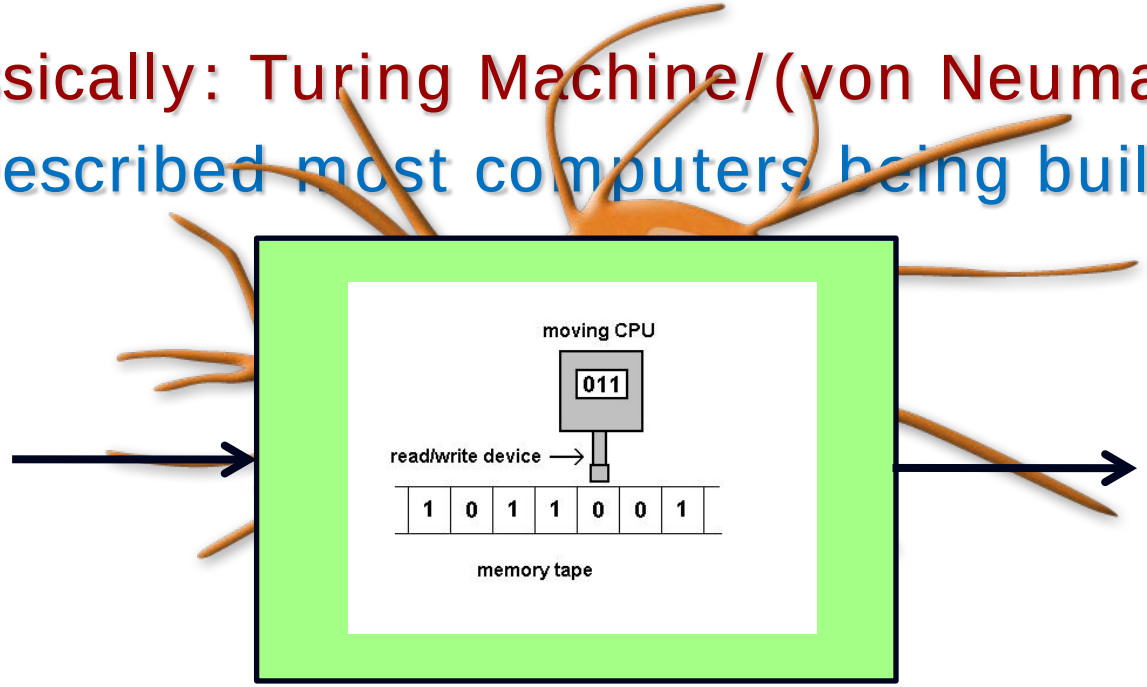


Communication: Ex. 4 (Intelligence?)



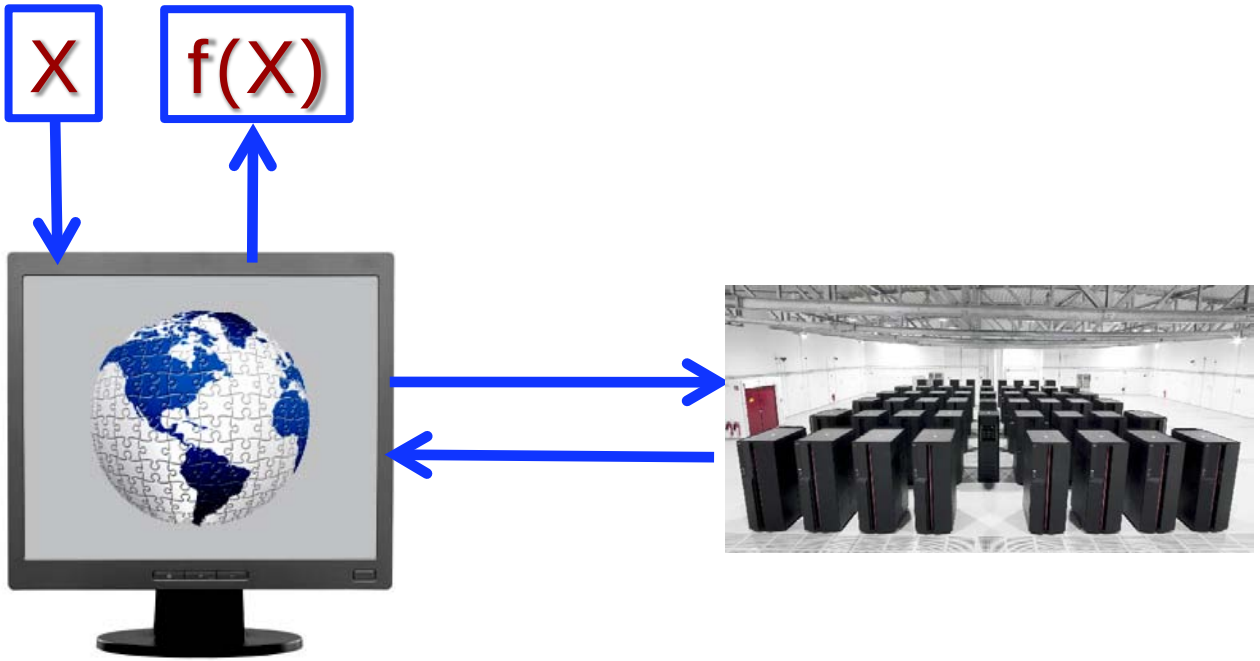
Aside: Modelling Computing

- Classically: Turing Machine/(von Neumann) RAM.
  - Described most computers being built?



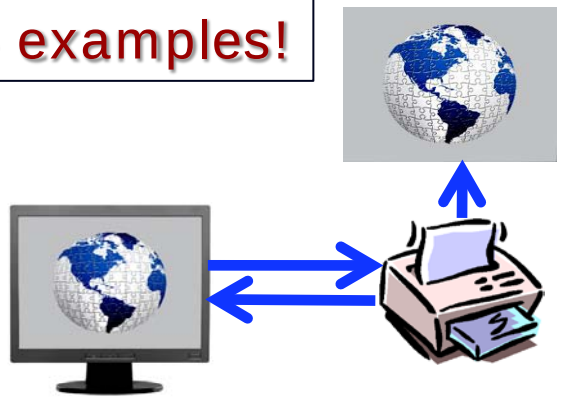
- Modern computers: more into communication than computing.
  - What is the mathematical model of a communicating computer?
  - What is universality?

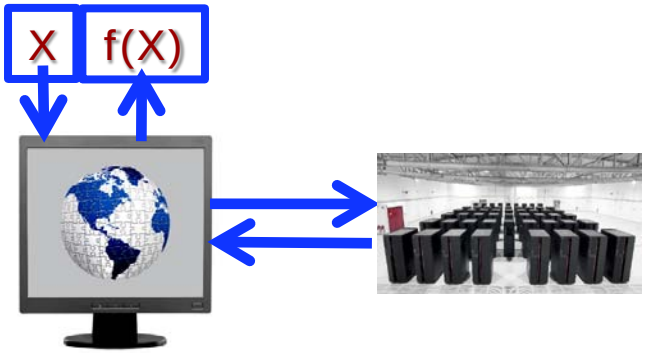
Communication: Ex. 2 (Computation)

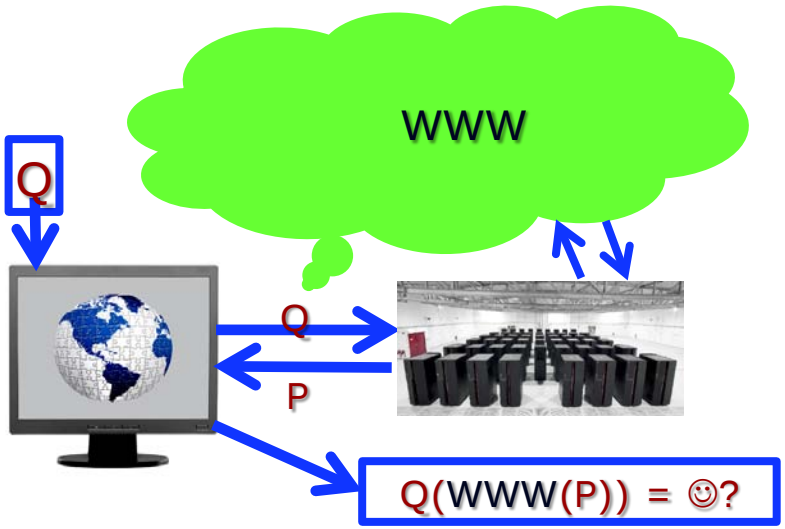


Generic communication problem?

Should model
All 4 examples!



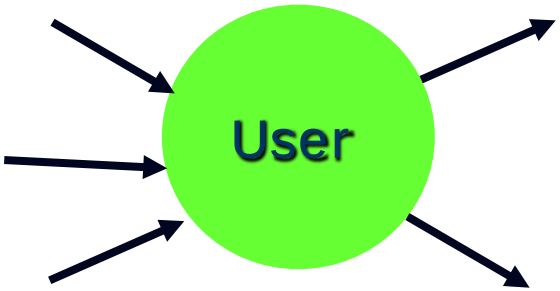




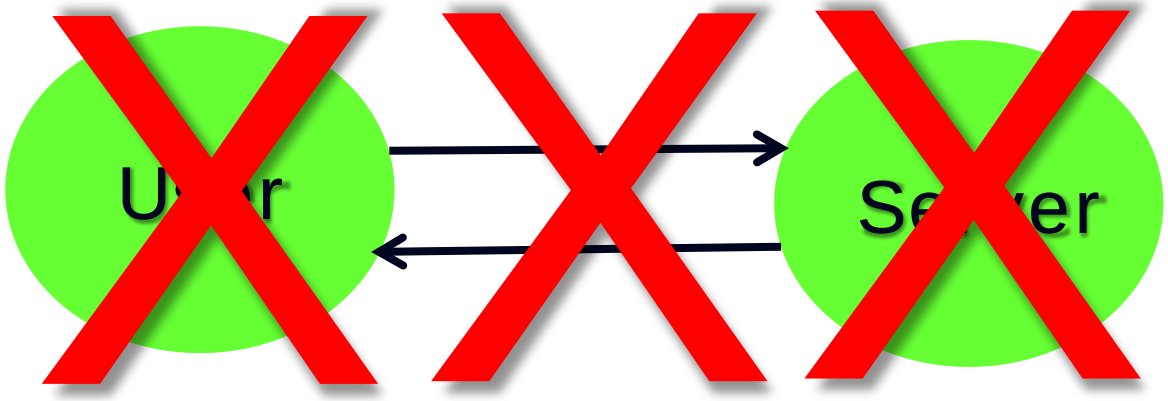
Modelling User / Interacting agents

- (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.



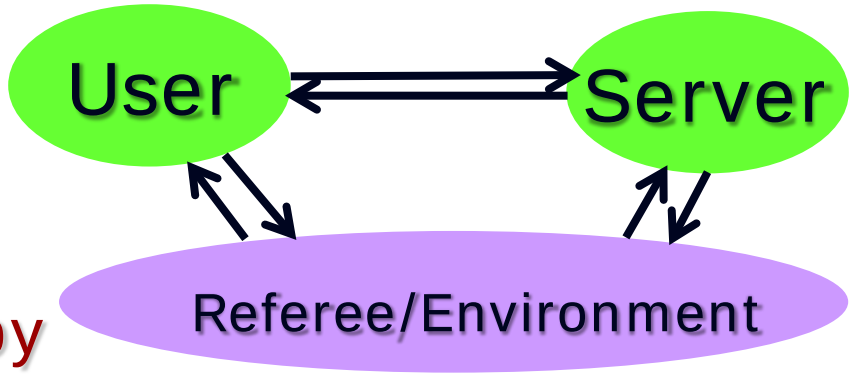
Generic Goal?



- 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

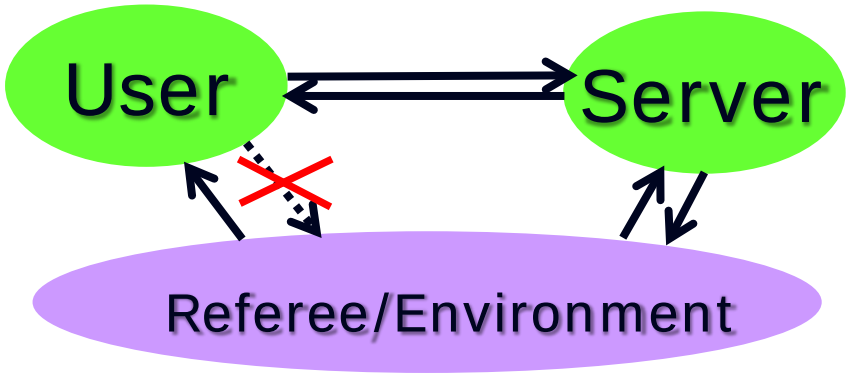
- Key Idea: Introduce 3rd entity: Referee
  - Poses tasks to user.
  - Judges success.



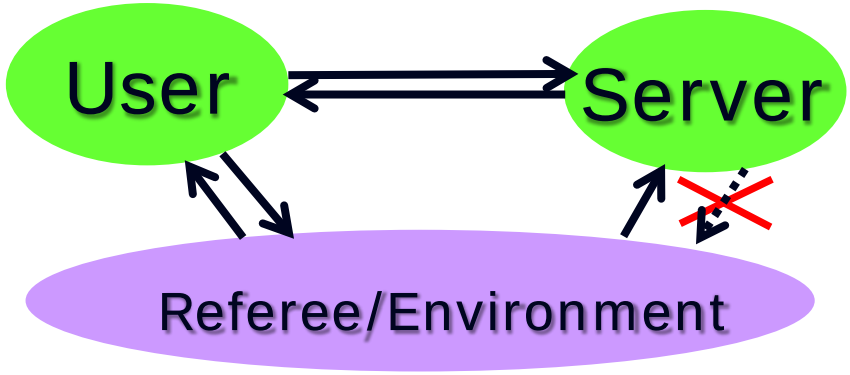
- Generic Goal specified by
  - Referee (just another agent)
  - Boolean Function determining if the state evolution of the referee reflects successful achievement of goal.
  - Class of users/servers.

Generic Goals

- Pure Control



- Pure Informational



Sensing & Universality

- To achieve goal, User should be able to sense progress.
  - I.e., user should be compute a function that (possibly with some delay, errors) reflects achievement of goals.
- Generalization of positive result:
  - Generic goals (with technical conditions) universally achievable if ∃ sensing function.
- Generalization of negative result:
  - Sensing is necessary (in one-shot goals)
  - (In infinite goals, If non-trivial generic goal is achieved with sufficiently rich class of helpful servers, then it is safely achieved with every server.)

Conclusions

- Is there a universal communication protocol?
  - No! (All functions vs. PSPACE-computable functions).
  - But can achieve "sensible" goals universally.
  - But … diversity of goals may be the barrier to universality.

- Goals of communication.
  - Should be studied more.
  - Suggests good heuristics for protocol design:
    - Server = Helpful?
    - User = 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!

References

- Juba & S.
  - ECCC TR07-084: http://eccc.uni-trier.de/report/2007/084/
- Goldreich, Juba & S.
  - ECCC TR09-075: http://eccc.uni-trier.de/report/2009/075/

Thank You!