Universal Semantic Communication

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An fantasy setting (SETI)

Alice

01001010101000111100100 0

No common language!
Is meaningful
communication possible?

Bob

What should Bob's response be?

If there are further messages, are they reacting to him?

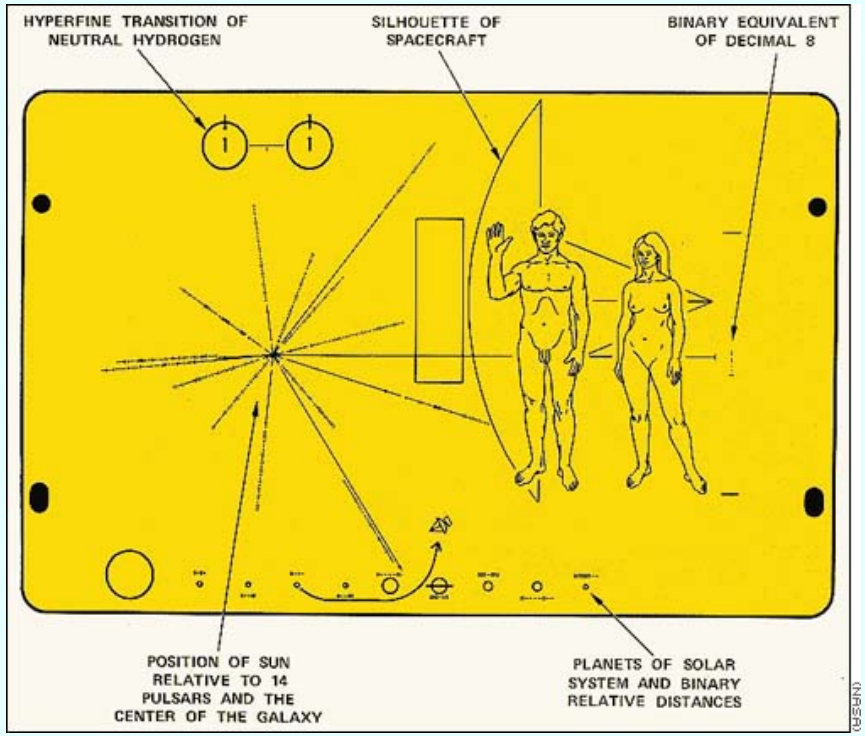
Is there an intelligent Alien (Alice) out there?

Pioneer's face plate

Why did they put this image?

What would you put?

What are the assumptions and implications?



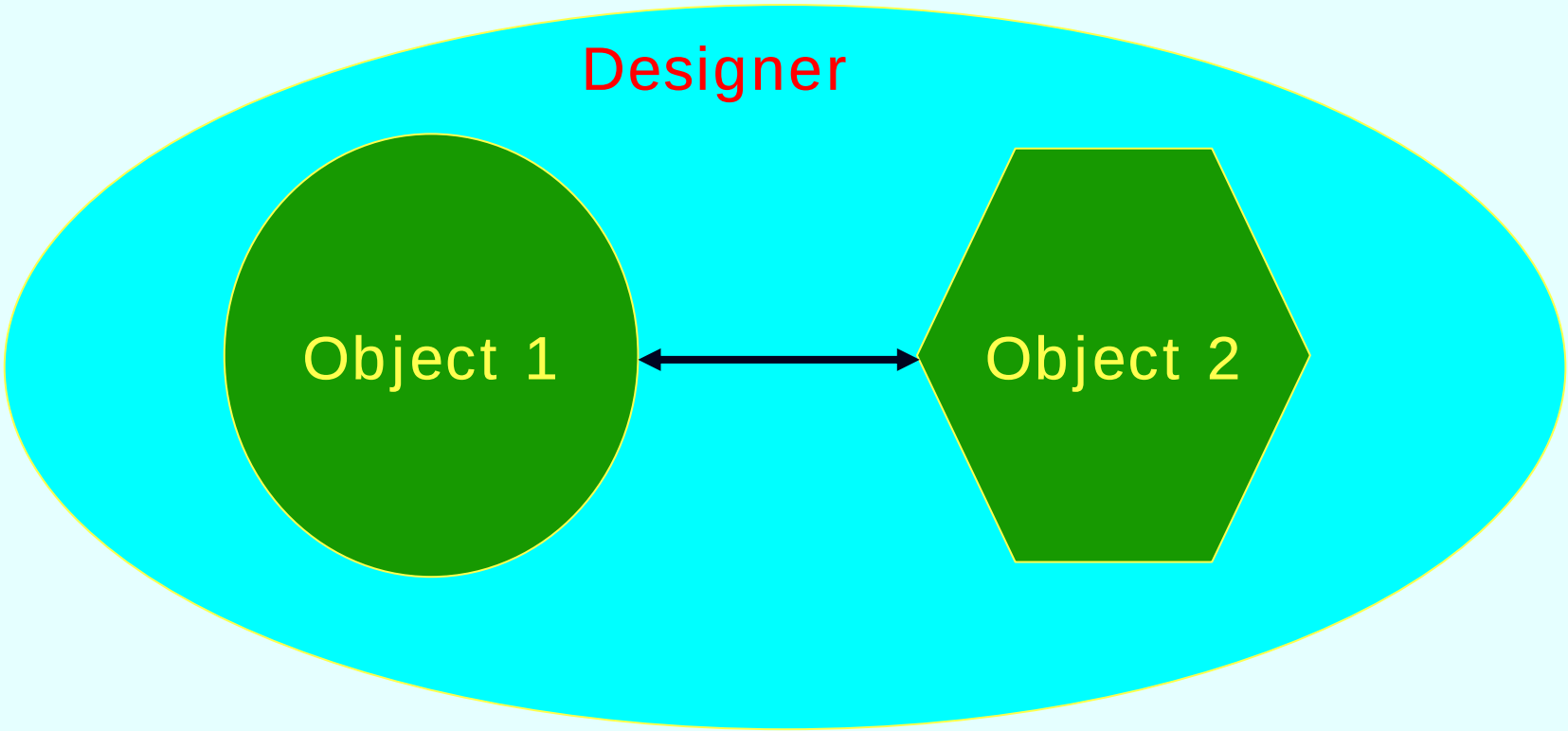
Motivation: Better Computing

- Networked computers use common languages:
  - Interaction between computers (getting your computer onto internet).
  - Interaction between pieces of software.
  - Interaction between software, data and devices.

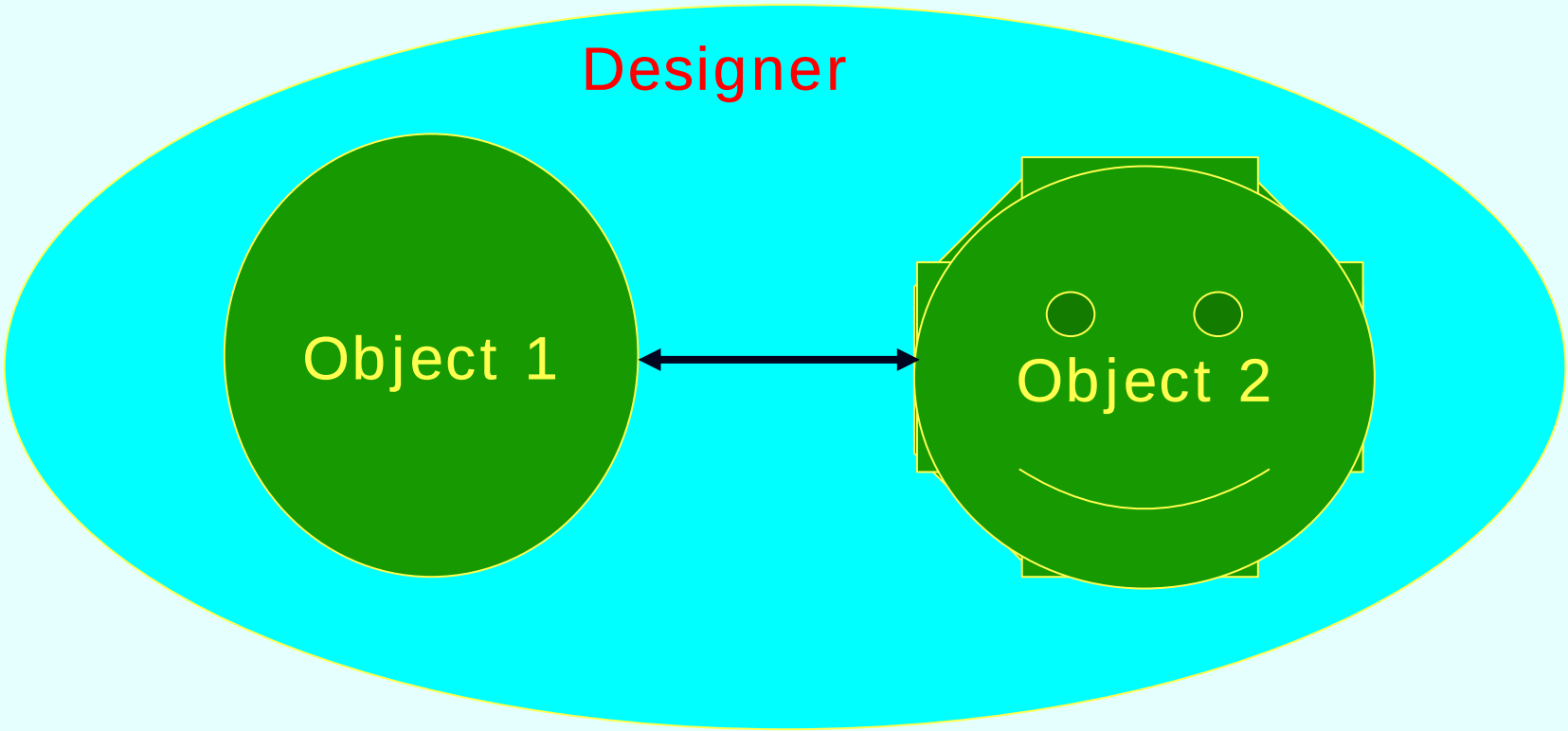
- Getting two computing environments to “talk” to each other is getting problematic:
  - time consuming, unreliable, insecure.

- Can we communicate more like humans do?

Classical Paradigm for interaction



New paradigm



Robust interfaces

- Want one interface for all “Object 2”s.
- Can such an interface exist?
- What properties should such an interface exhibit?
- Puts us back in the “Alice and Bob” setting.

Goal of this talk

- Definitional issues and a definition:
  - What is successful communication?
  - What is intelligence? cooperation?
- Theorem: “If Alice and Bob are intelligent and cooperative, then communication is feasible” (in one setting)
- Proof ideas:
  - Suggest:
    - Protocols, Phenomena …
    - Methods for proving/verifying intelligence

What has this to do with computation?

- **In general**: Subtle issues related to "human" intelligence/interaction are within scope of computational complexity. E.g.,
  - Proofs?
  - Easy vs. Hard?
  - (Pseudo)Random?
  - Secrecy?
  - Knowledge?
  - Trust?
  - Privacy?

- **This talk**: What is "understanding"?

A first attempt at a definition

- Alice and Bob are “universal computers” (aka programming languages)
- Have no idea what the other’s language is!
- Can they learn each other’s language?

- Good News: Language learning is finite. Can enumerate to find translator.

- Bad News: No third party to give finite string!
  - Enumerate? Can’t tell right/wrong ☹

Communication & Goals

- Indistinguishability of Right/Wrong: Consequence of “communication without goal”.
- Communication (with/without common language) ought to have a “Goal”.
- Before we ask how to improve communication, we should ask why we communicate?

“Communication is not an end in itself,

but a means to achieving a Goal”

Part I: A Computational Goal

Computational Goal for Bob

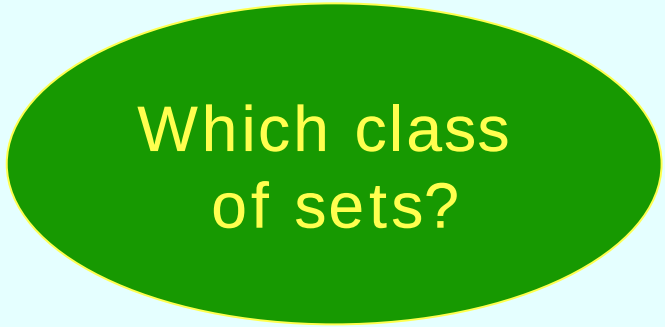
- Bob wants to solve hard computational problem:
  - Decide membership in set S.
- Can Alice help him?
- What kind of sets S? E.g.,
  - S = {set of programs P that are not viruses}.
  - S = {non-spam email}
  - S = {winning configurations in Chess}
  - S = {(A,B) | A has a factor less than B}

Review of Complexity Classes

- **P (BPP)** – Solvable in (randomized) polynomial time (Bob can solve this without Alice's help).
- **NP** – Problems where solutions can be verified in polynomial time (contains factoring).
- **PSPACE** – Problems solvable in polynomial space (quite infeasible for Bob to solve on his own).
- **Computable** – Problems solvable in finite time. (Includes all the above.)
- **Uncomputable** (Virus detection. Spam filtering.)

Which problems can you solve
with (alien) help?

Setup

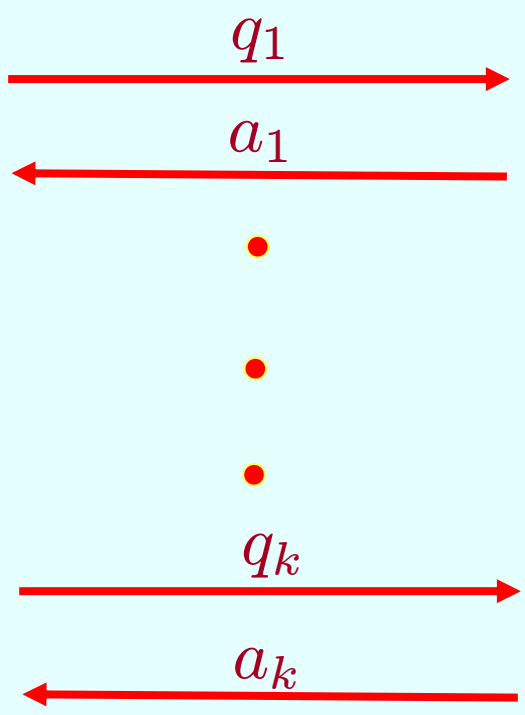


Alice

Bob

$x \in S?$

$R \leftarrow \$\$\$$



$f(x, R, a_1, \ldots, a_k) = 1?$

Hopefully $x \in S \Leftrightarrow f(\cdots) = 1$

Contrast with Interactive Proofs

- Similarity: Interaction between Alice and Bob.
- Difference: In IP, Bob does not trust Alice.
  (In our case Bob does not understand Alice).

- Famed Theorem: IP = PSPACE [LFKN, Shamir].
  - Membership in PSPACE solvable S can be proved interactively to a probabilistic Bob.
  - Needs a PSPACE-complete prover Alice.

Intelligence & Cooperation?

- For Bob to have a non-trivial interaction, Alice must be:
  - Intelligent: Capable of deciding if x in S.
  - Cooperative: Must communicate this to Bob.
- Modelling Alice: Maps "(state of mind,external input)" to "(new state of mind, output)".
- Formally:

Alice is S-helpful

if $\exists$ probabilistic poly time (ppt) Bob B' s.t.

$\forall$ initial state of mind σ,

$A(\sigma) \leftrightarrow B'(x)$ accept w.h.p. iff $x \in S$.

Successful universal communication

- **Bob should be able to talk to any S-helpful Alice and decide S.**

- **Formally,**

  Ppt B is S-universal if for every $x \in \{0,1\}^*$

  - A is S-helpful $\Rightarrow$ $[A \leftrightarrow B(x)] = 1$ iff $x \in S$ (whp).

    A is not S-helpful $\Rightarrow$ Nothing!!

  Or should it be ...

  A is not S-helpful $\Rightarrow [A \leftrightarrow B(x)] = 1$ implies $x \in S$.

Main Theorem

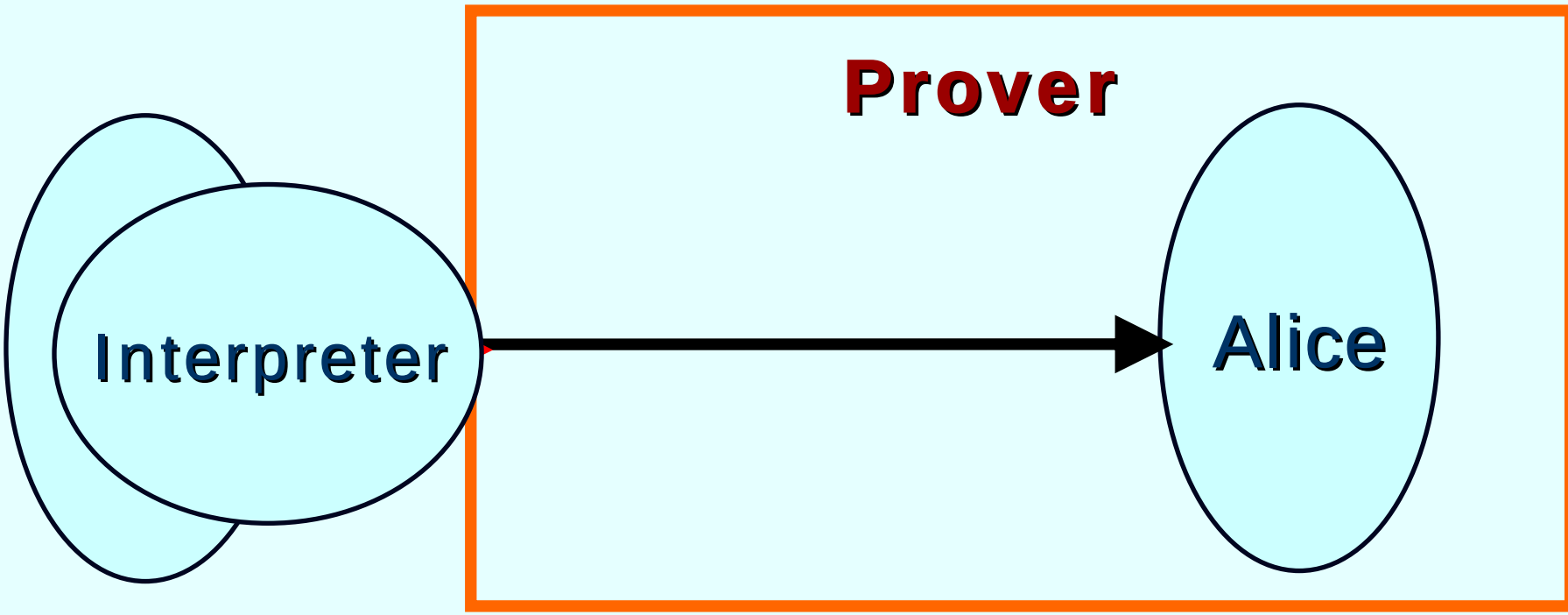
- If S is PSPACE-complete (aka Chess),
  then there exists an S-universal Bob.
  (Generalizes to any checkable set S.)
- If there exists an S-universal Bob
  then S is in PSPACE.

- **In English:**
  - **If S is moderately stronger than what Bob can do on his own, then attempting to solve S leads to non-trivial (useful) conversation.**
  - **If S too strong, then leads to ambiguity.**
  - **Uses IP=PSPACE**

Few words about the proof

- **Positive result: Enumeration + Interactive Proofs**

Guess: Interpreter; $x \in S$?



Proof works $\Rightarrow x \in S$; Doesnt work $\Rightarrow$ Guess wrong.
Alice S-helpful $\Rightarrow$ Interpreter exists!

Proof of Negative Result

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

Potential Criticisms of Main Theorem

- This is just rephrasing IP=PSPACE.
  - No ... the result proves “misunderstanding is equal to mistrust”. Was not a priori clear.
    - Even this is true only in some contexts.

Potential Criticisms of Main Theorem

- This is just rephrasing IP=PSPACE.

- Bob is too slow: Takes exponential time in length of Alice, even in his own description of her!
  - A priori – not clear why he should have been able to decide right/wrong.
  - Polynomial time learning not possible in our model of "helpful Alice".
  - Better definitions can be explored – future work.

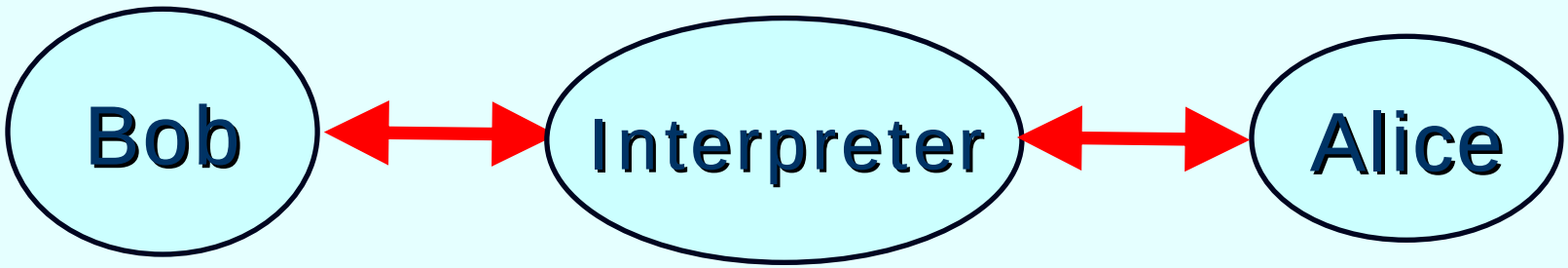
Potential Criticisms of Main Theorem

- This is just rephrasing IP=PSPACE.
- Bob is too slow: Takes exponential time in length of Alice, even in his own description of her!
- Alice has to be infinitely/PSPACE powerful ...
  - But not as powerful as that Anti-Virus Program!
  - Wait for Part II

Part II: Intellectual Curiosity

Setting: Bob more powerful than Alice

- What should Bob's Goal be?
  - Can't use Alice to solve problems that are hard for him.
  - Can pose problems and see if she can solve them. E.g., Teacher-student interactions.
  - But how does he verify "non-triviality"?
  - What is "non-trivial"? Must distinguish ...



Scene 1

Setting: Bob more powerful than Alice

- Concretely:
  - Bob capable of TIME(n^{10}).
  - Alice capable of TIME(n^3) or nothing.
  - Can Bob distinguish the two settings?

- Answer: Yes, if Translate(Alice,Bob) computable in TIME(n^2).
  - Bob poses TIME(n^3) time problems to Alice and enumerates all TIME(n^2) interpreters.

- Moral: Language (translation) should be simpler than problems being discussed.

Part III: Concluding thoughts

Is this language learning?

- End result promises no language learning: Merely that Bob solves his problem.
- In the process, however, Bob learns Interpreter!
- But this may not be the right Interpreter.
- All this is Good!
  - No need to distinguish indistinguishables!

Goals of Communication

- Largely unexplored (at least explicitly)!

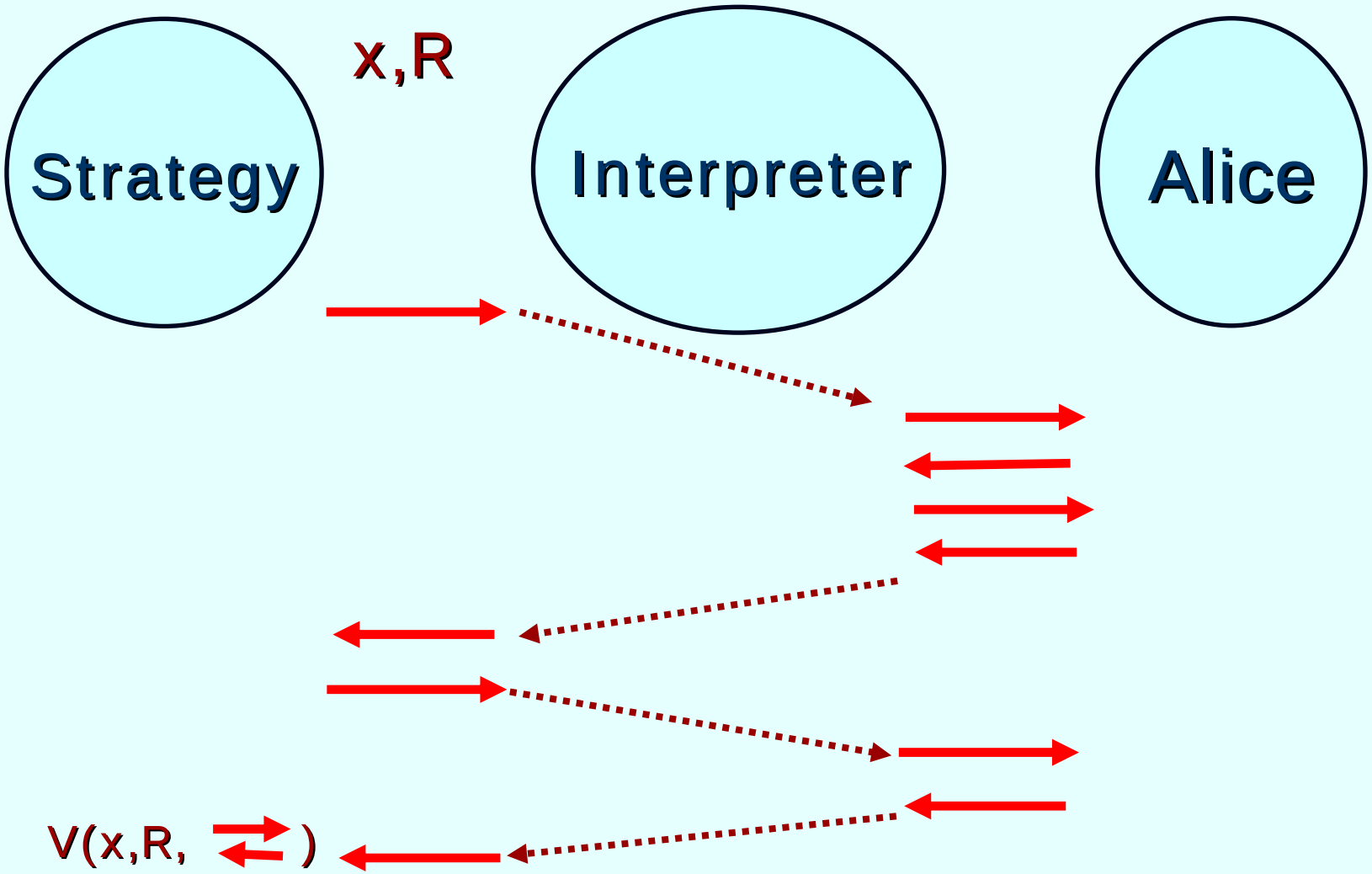
- Main categories
  - Remote Control:
    - Laptop wants to print on printer!
    - Buy something on Amazon
  - Intellectual Curiosity:
    - Learning/Teaching
    - Listening to music, watching movies
    - Coming to this talk
    - Searching for alien intelligence
  - May involve common environment/context.

Extension to generic goals

- Generic (implementation of) Goal: Given by:
  - Strategy for Bob.
  - Class of Interpreters.
  - Boolean function G of
    - Private input, randomness
    - Interaction with Alice through Interpreter
    - Environment (Altered by actions of Alice)

- Should be
  - Verifiable: G should be easily computable.
  - Complete: Achievable w. common language (for some Alice, independent of history).
  - Non-trivial: Not achievable without Alice.

Generic Verifiable Goal



Verifiable Goal = (Strategy, Class of Interpreters, V)

Generic Goals

- Can define Goal-helpful; Goal-universal; and prove existence of Goal-universal Interpreter for all Goals.
- Claim: Captures all communication
  (unless you plan to accept random strings).
- Modelling natural goals is still interesting. E.g.
  - Printer Problem: Bob(x): Alice should say x.
  - Intellectual Curiosity: Bob: Send me a "theorem" I can't prove, and a "proof".
  - Proof of Intelligence (computational power):
    Bob: given f, x; compute f(x).
- Conclusion: (Goals of) Communication can be achieved w/o common language

Role of common language?

- If common language is not needed (as we claim), then why do intelligent beings like it?
  - Our belief: To gain efficiency.
    - Reduce # bits of communication
    - # rounds of communication

- Topic for further study:
  - What efficiency measure does language optimize?
  - Is this difference asymptotically significant?

Further work

- Exponential time learning (enumerating Interpreters)
  - What is a reasonable restriction on languages?
- What are other goals of communication?
- What are assumptions needed to make language learning efficient?

Paper (Part I) available from ECCC

Thank You!