Universal *Semantic* Communication

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An fantasy setting (SETI)

Alice

01001010101000111100100 0

No common language!
Is meaningful
communication possible?

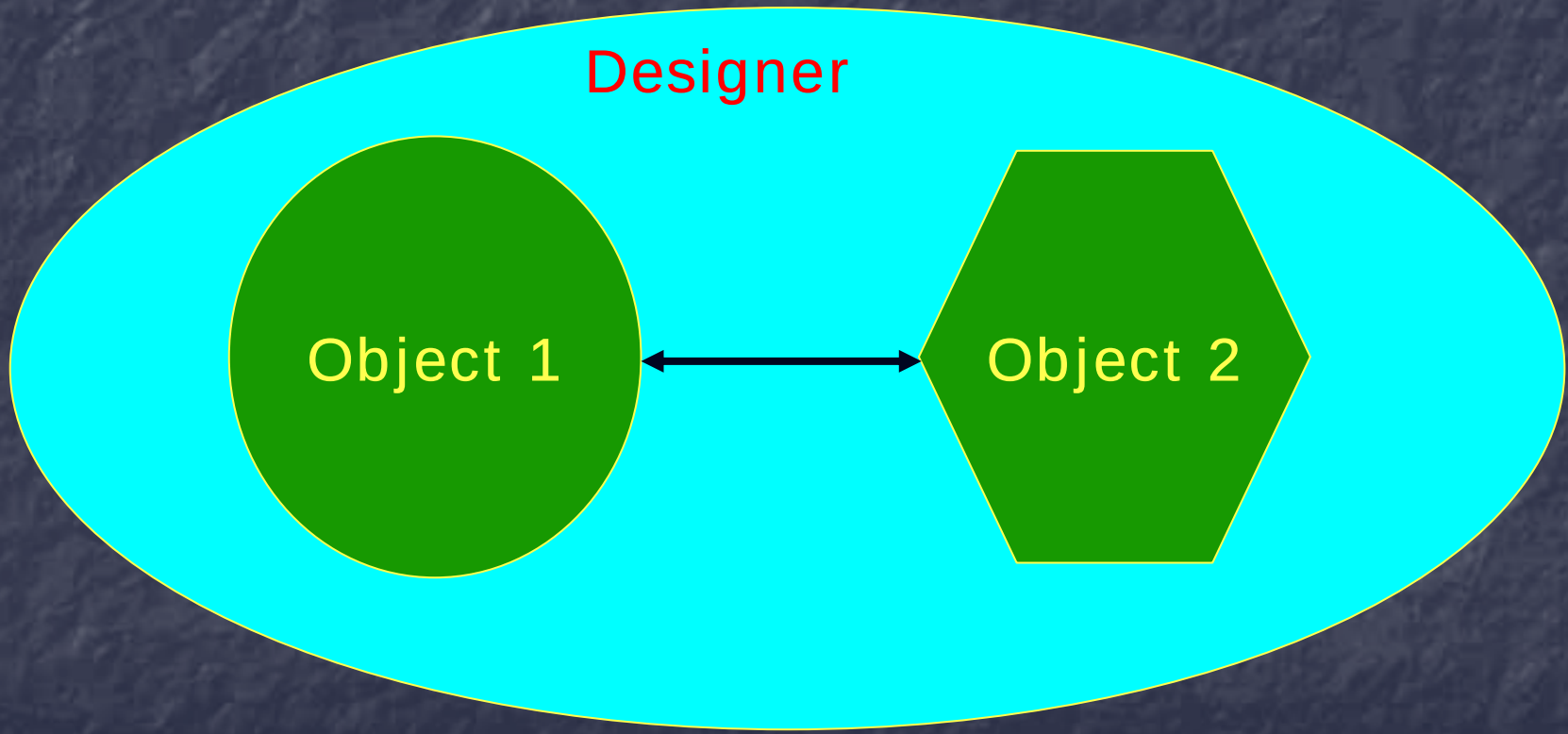
Bob

What should Bob's response be?

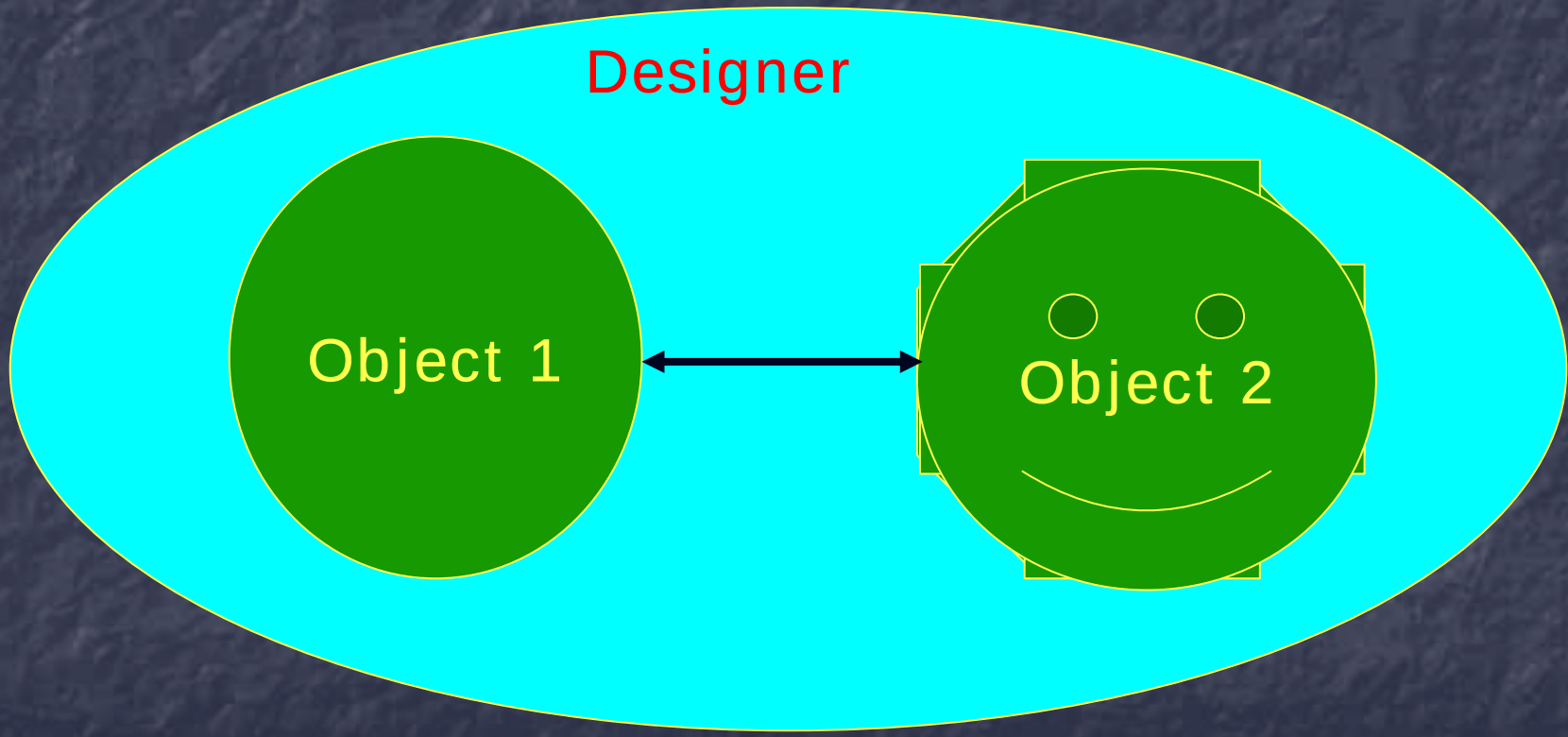
If there are further messages, are they reacting to him?

Is there an intelligent Alien (Alice) out there?

Classical Paradigm for interaction



New paradigm



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

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”

Setup

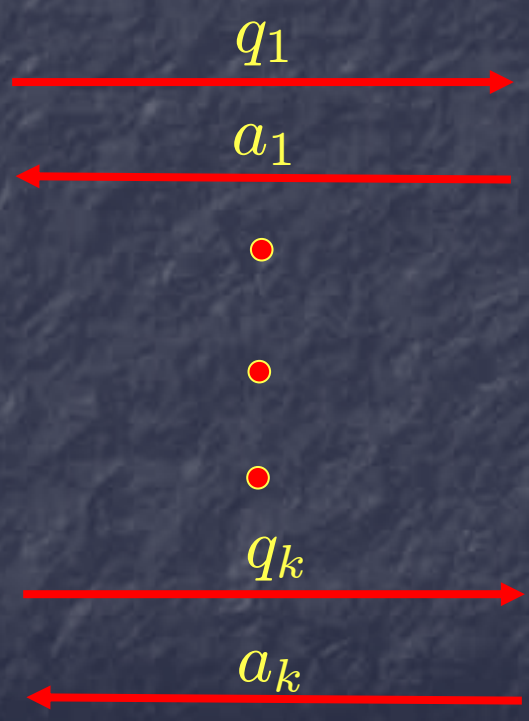
Which class of sets?

Bob

Alice

$x \in S?$

$R \leftarrow \$\$\$$



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

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.

- Formally:

  Alice is S-helpful
  if $\exists$ probabilistic poly time (ppt) Bob B' s.t.
  For all states σ of Alice
  $A(\sigma) \leftrightarrow B'(x)$ 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 $x \in \{0,1\}^*$

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

  – (For S-helpful A) $[A \leftrightarrow B(x)] = 1$ w.h.p. $\Rightarrow x \in S$.

Main Theorem

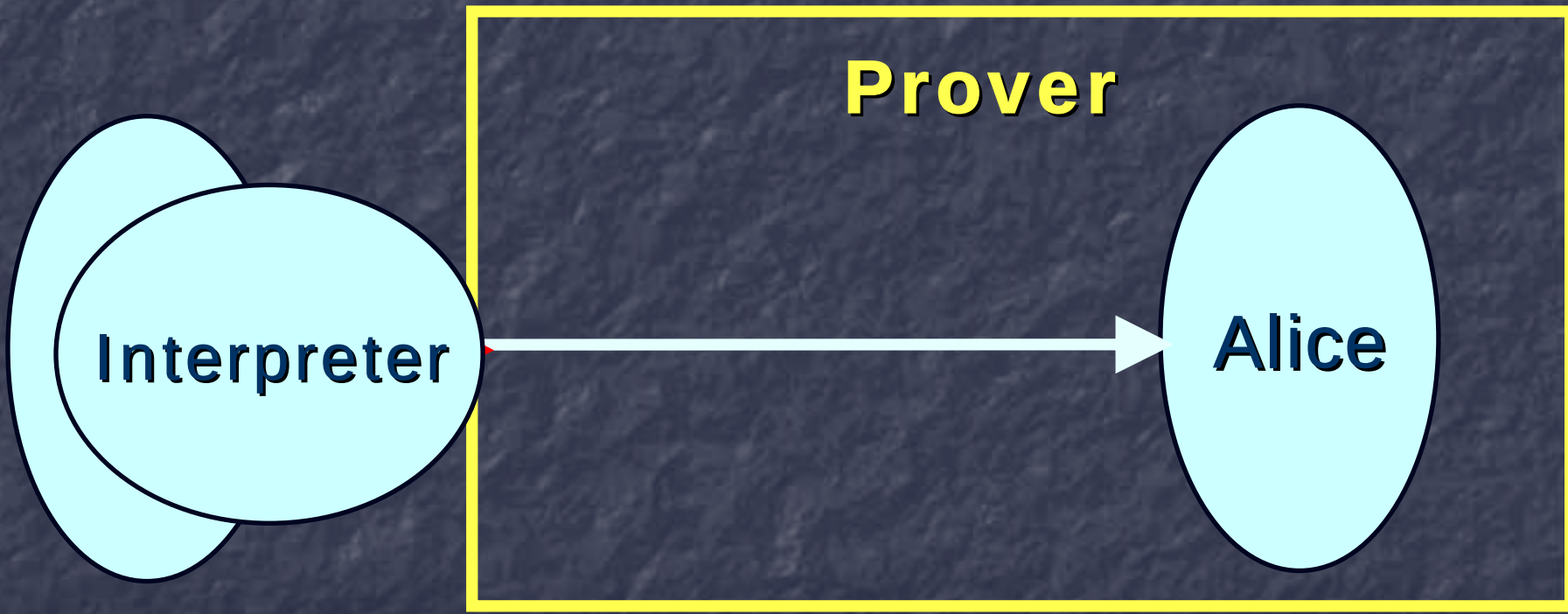
- - If S is PSPACE-complete (aka Chess),
  then there exists an S-universal Bob.
  (Generalizes to any checkable set S.)
- - If there exists an S-universal Bob
  then S is in PSPACE.

- 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!

Few words about the proof

- Positive result: Enumeration + Interactive Proofs
- Negative result:
  - 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.
  - Decision can be computed 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.

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!