Grounding knowledge in subjective experience

Rich Sutton
University of Alberta

Is the ultimate meaning of a representation

what it means to the agent?

or what it means to its human designers?

Reinforcement Learning

subjective, private representations

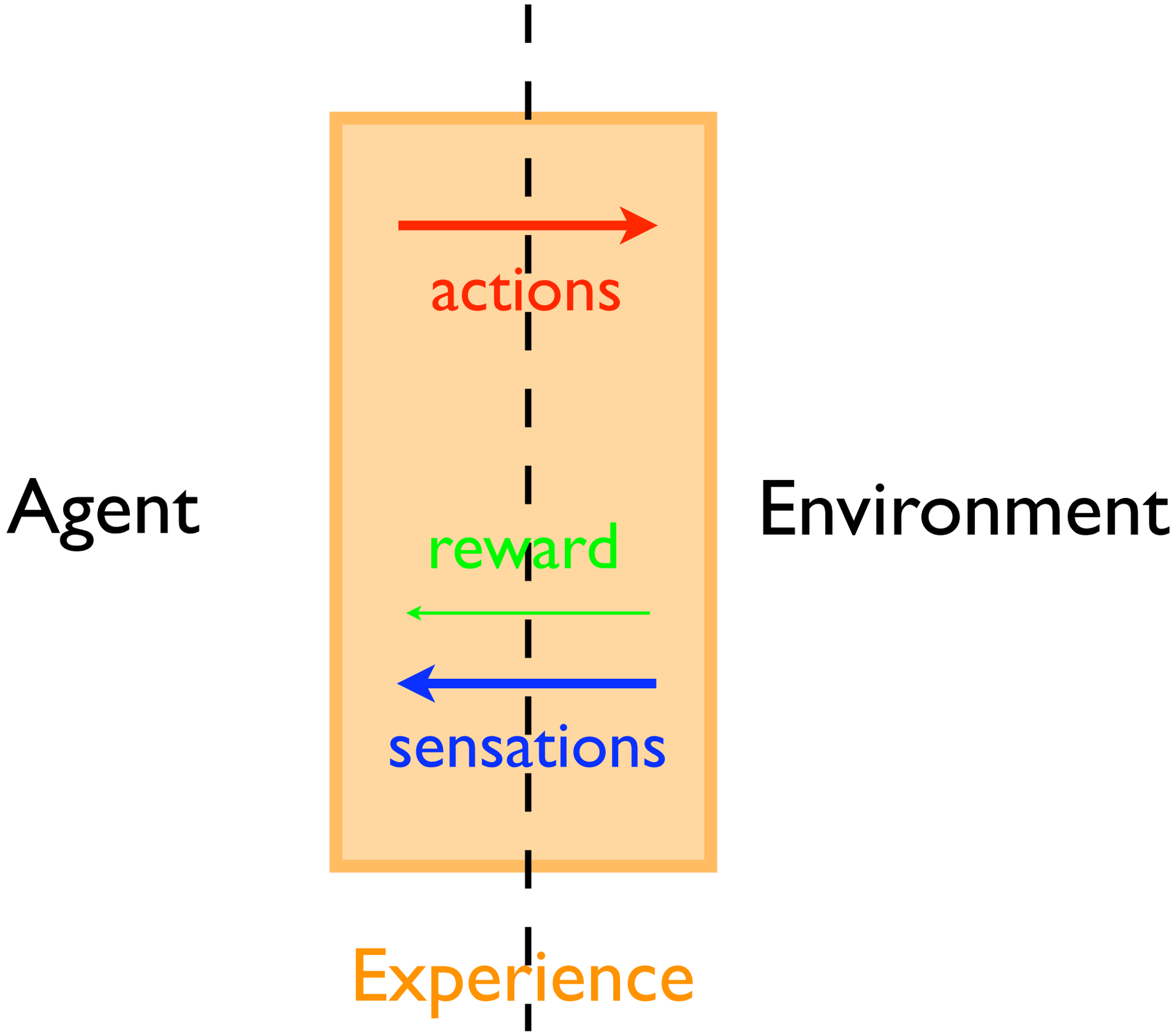
Knowledge Representation

objective, public representations

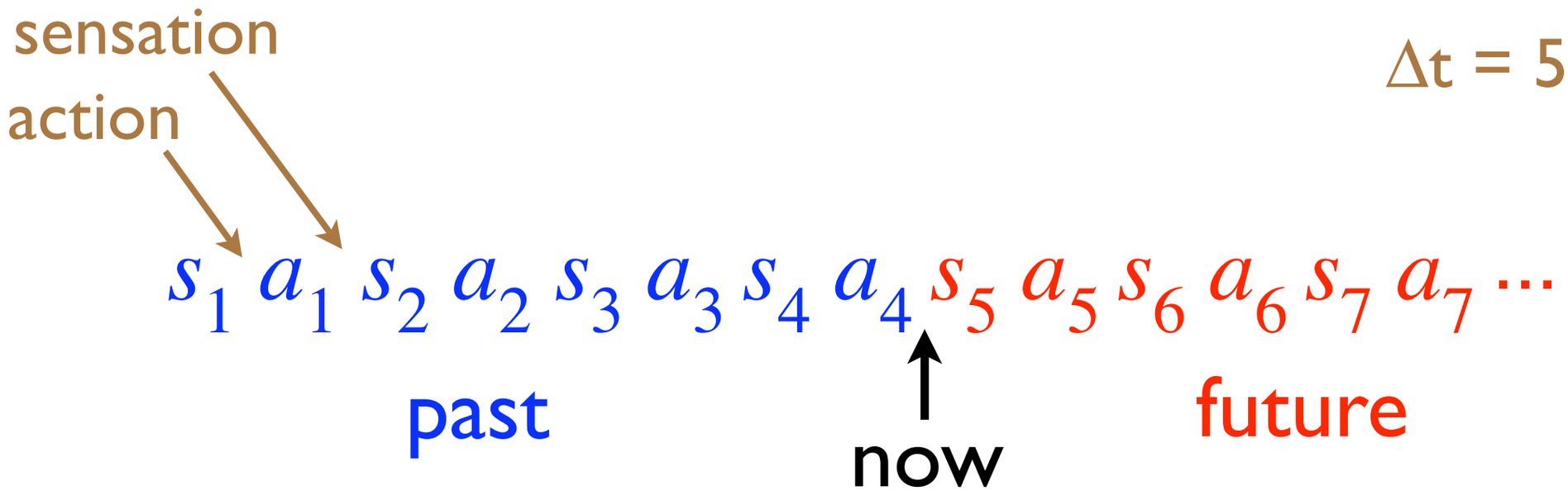
The Problem

- How can we represent complex, commonsense knowledge of the world?
- With mathematical clarity
  - With meaning is as clear as that of a transition probability
- In such a way that it is maintainable without continuous human intervention
- In such a way that it can be learned and used flexibly (e.g., for planning)

The key to a successful AI is that it can tell for itself whether it is working correctly


actions
Agent
Environment
reward
sensations
Experience

Experience (the data of AI)



The temporal stream of
lowest-level sensori-motor experience

Experience matters

- Experience is the most prominant feature of the computational problem we call AI
- It's the central data structure
- It has a definite temporal structure
  - revealed and chosen over time
  - speed of decision is important
  - order is important
- This has unavoidable implications for AI

Experiential knowledge hypothesis:

All world knowledge is a prediction or memory of sensori-motor experience

- Knowledge is subjective
- Knowledge is ultimately low-level
- Logic and math are not world knowledge
  - they are true in any world

A Grand Challenge:

Grounding knowledge in experience

- To represent human-level world knowledge solely in terms of lowest-level experience
  - sensations
  - actions
  - time
- A minimal ontology
  - no objects, no people, no space, no self, no chickens...
  - all these are "just" patterns in sensation & action

What would it be like to accept the challenge?

- Abstraction is key
  - abstract states (eg, predictive representations)
  - abstract actions/transitions (eg, options)
- Need to think in unfamiliar ways
- Microworlds, robotics
- Indexical (deictic) representations
  - sequence instead of symbols

In subjective terms,

- What is space?
  - regularities in sensation change with eye movement
- What are objects?
  - subsets of sensations
  - that tend to occur together temporally
  - and can be in arbitrary relative spatial arrangements

- What is my body, my hands?
  - objects that are always present
  - and can be controlled
- What are people?
  - objects that may move on their own
  - that have a particular subset of sensations
  - whose presence may change my sensations for the better
  - eventually:
    - ✦ that are best predicted with respect to goals
    - ✦ that are analogous to me

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Relational ⇒ Indexical

∀ objects X, If I drop X, then X will be on the floor

- Holding object X means predicting certain sensations if, for example, one directs one's eyes toward one's hand
- Thus, on dropping, the predicted sensations are merely transferred from the looking-at-hand prediction to the looking-at-floor prediction
- Such transfer of existing predictions should be a common part of visual knowledge - updated every time the eyes move

∃ X,Y, such that Red(X), Blue(Y), and Above(X,Y)

- There is some place I can foveate and see Red
- There is some place I can foveate and see Blue
- If I foveate first the Red place, "mark" it, then the Blue place, the mark will be *above* the fovea (repeat until succeeds)

These are typical ideas of modern, active, deictic vision

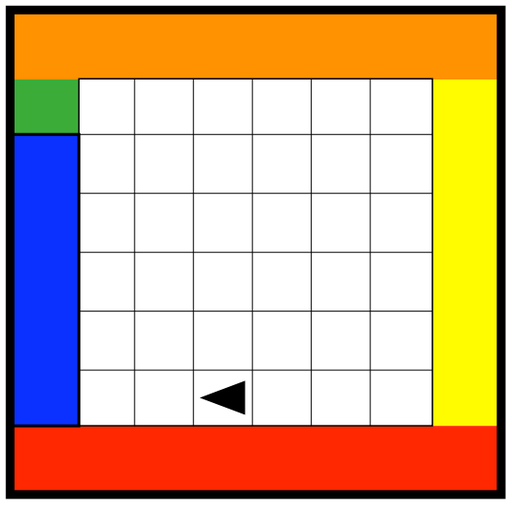
Explicit Prediction Manifesto

Every prediction is a question and an answer, and both the question and the answer must be *explicit* in the sense of being accessible to the AI agent, i.e., of being machine readable, interpretable, and usable

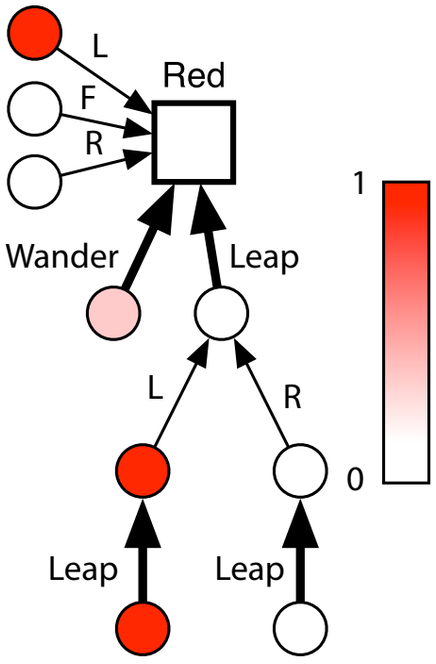
Temporal-difference networks

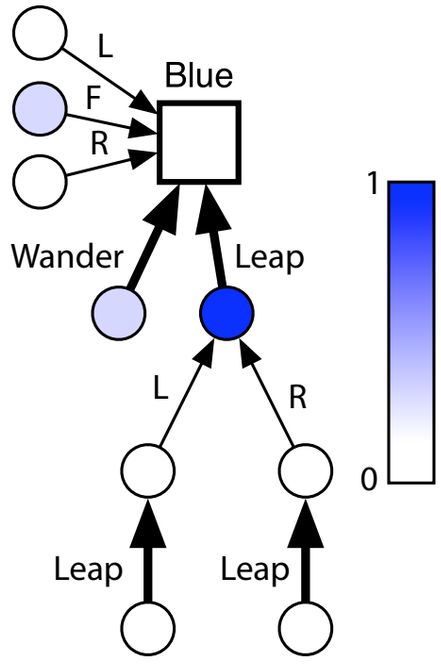
- Main idea: separate the problem of prediction into questions and answers, two networks
- The *question network* represents the explicit meaning of predictions
  - inter-predictive temporal relationships
  - can be used to represent a wide range of compositional, abstract, predictive questions
- The *answer network* computes estimates of the predictions

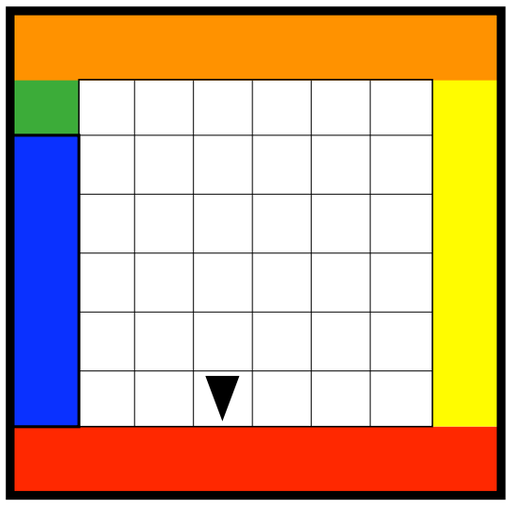
World

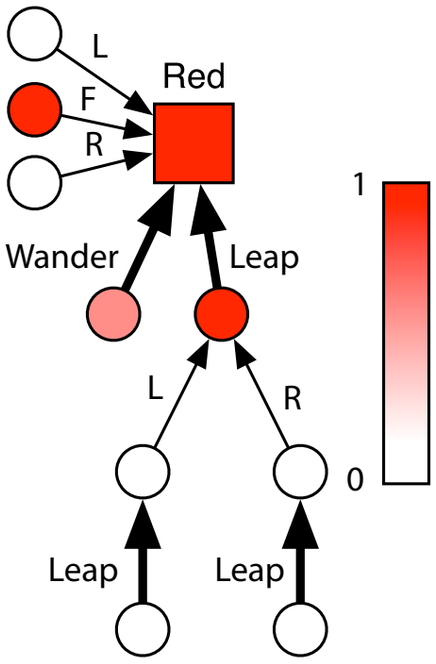


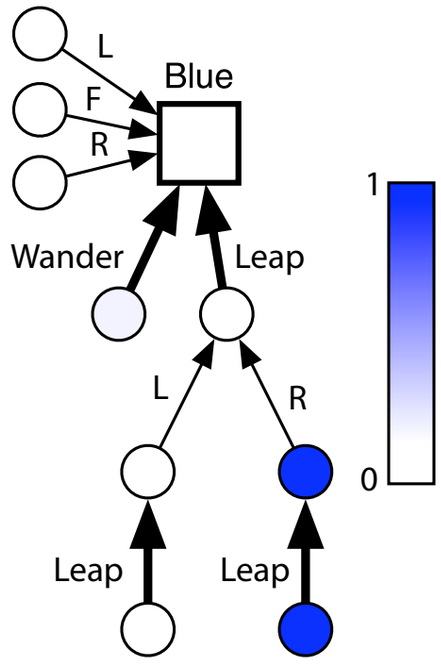
Question network











sensation: color ahead
actions: L(eft), R(ight), F(orward)
options: Leap (to wall), Wander (randomly)

Pros and cons of subjective grounding of knowledge

- Loses
  - easy expressiveness
  - coherence with people
  - interpretability, explainability
- Gains
  - the knowledge means something to the machine
  - can be mechanically maintained/verified/tuned/learned
  - suitable for general-purpose reasoning methods

There is no middle way

- Every step we take towards objective, public representations takes us farther away from the power and potential of subjective representations
- Public representations are good for everything *except* AI

Subjective doesn't mean you can't build it in

- Subjective ≠ learned
- You can build knowledge in, but you must build it in subjective terms rather than in public, consensual, "objective" terms
- The subjective must be there

Summary

- Subjective experience is the data of AI
  - it's crazy to try to do AI without experience
- Subjective (predictive) knowledge is powerful
  - automatically verifiable, tunable, extendable, learnable
  - explicit, machine-readable semantics
  - can be built in
- Abstraction is key – in state and time
- Grounding knowledge is a grand challenge