How can we compare intelligence of two machines?

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The term 'Intelligence' is everywhere!

Lots of papers claim an intelligence

How intelligent?

Which agent is more intelligent?

E.g. Intelligent decision in stock market

Sewell "The Application of intelligent systems to financial time series analysis."

Tsang "Forecasting - where computational intelligence meets the stock market."

Kuoa "An intelligent stock trading decision support system."

Or, would it be better to ask monkey to throw darts?

Malkiel "A Random Walk Down Wall Street"

"A monkey throwing darts at the WSJ to select a portfolio might be better than the one carefully selected by experts."

$\Downarrow$

Those machines would be less intelligent than a monkey

Other examples we want to know its intelligence

From
Deep Blue: beat Kasparov
to
Watson: won Jeopardy
Dr. Fill: joined the human crossword tournament
Siri: incorpolated in i-Phone 4

Essay-scoring software

A degree to how a machine is intelligent

Gregory Chaitin (1987), Warren Smith (2006)
tried to answer it using complexity theory.

$\Downarrow$

Now we have a fair amount of such definitions.

Legg & Hutter's definition

From informal

"An agent's ability to achieve goals in a wide range of environments."

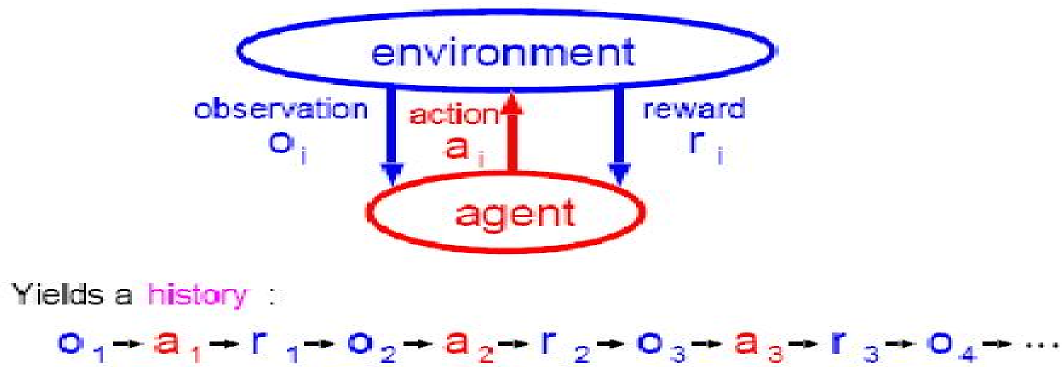
$\Downarrow$

to formal

$$\gamma(\pi) = \sum_{\mu \in E} 2^{-K(\mu)} \cdot V_\mu^\pi$$

Agent interacts with environment

Observation $o_i \Rightarrow$ Action $a_i \Rightarrow$ Reward r_i



Definition of agent

Function that takes the current history as input
and
produces an action as output

$$\pi(a_k|o_1r_1a_1o_2r_2a_2\cdots o_{k-1}r_{k-1})$$

or probability function for indeterministic.

Definition of environment

Function which produces output $o_k r_k$ given the current history

$$\mu(o_k r_k | o_1 r_1 a_1 o_2 r_2 a_2 \cdots o_{k-1} r_{k-1} a_{k-1})$$

or probability function for indeterministic.

Expected value of sum of rewards

$$V_\mu^\pi = E(\sum_{i=1}^{\infty} r_i)$$

after each repetion of

$$o_i \to a_i \to r_i.$$

Definition of intelligence

Weighted sum of
expected value of sum of rewards over infinite environments

$$\gamma(\pi) = \sum_{\mu \in E} w_\mu \cdot V_\mu^\pi$$

How will those weights be specified?

Translate the environment into a binary string x by Turing Machine U

$\Downarrow$

Calculate Kolmogorov complexity K of x

(length of the shortest program that computes x)

$$K(x) = \min_p\{l(p)|U(p) = x\}$$

$\Downarrow$

$$w_\mu = 2^{-K(\mu)}$$

The smaller the complexity the larger the weight $\Rightarrow$ Occam's razor

Universal Machine Intelligence

by Legg and Hutter

$$\gamma(\pi) = \sum_{\mu \in E} 2^{-K(\mu)} \cdot V_{\mu}^{\pi}$$

"An agent's ability to achieve goals in a wide range of environments."

Too conceptual or too theoretical

Goertzel:

"Universal but not practical."

Goertzel

pragmatic intelligence

$$\Pi(\pi) = \sum_{\mu \in E, g \in G, T} \nu(\mu)\gamma(g,\mu)\tau_{g,\mu}(T)V^{\pi}_{\mu,g,T}$$

$$\Downarrow$$

It's not very practical yet, isn't it?

Problem is, translation of environment by Turing machine

$\Downarrow$

Are there easier alternatives to the Turing machine?

Hernándes-Orallo

The other representations of environment

$\Downarrow$

(i) λ-calculus, (ii) combinatory logic, (iii) abstract state machines,
(iv) register machines, (v) Markov algorithms,
(vi) term-rewriting systems, ...

to generate environments and calculate complexity automatically.

"still Turing-complete, but
more natural and easy to work with than the Turing machine."

Hernandes's example

tests measures the ability of finding the shortest explanation for some strings of different difficulty in a fixed time

e.g.

$x = aaaaaaabaaaaaaaaaaaaaabaaa$

$x = aabbbccdddeefffgghhhiijjj$

$x = 1,2,3,5,7,11,13,17,19,23$

$\Downarrow$

Still not so practical for our purpose.

To proceed further (1)

First, let's be more practical!

Let's look for yet another way to measure complexity.

The other ways to measure complexity

although these are not Turing complete any more.

Crutchfield et al.: Comment on "Simple Measure for Complexity"

$$\Gamma_{\alpha\beta} = (S/S_{max})^{\alpha}(1 - (S/S_{max}))^{\beta}$$

Fioretti: A subjective measure of complexity

$$C_O(S) = \sum_{q=0}^{Q} \frac{q+1}{s_q}$$

Lloyd: A survey - Measures of complexity a non-exhaustive list

To proceed further (2)

Second, let's be specific not universal!

⋆ "She is an intelligent dancer,"
while we know she is not good at Mathematics,
which we don't care.

⋆ This conductor always makes an intelligent interpretation of symphony,
but very bad at football.

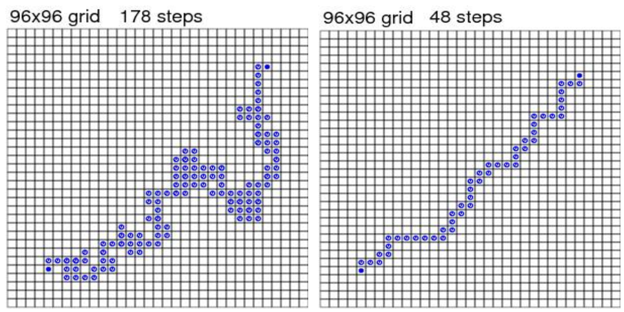
⋆ Would Einstein play tennis intelligently?

⇓

Intelligence doesn't need to be universal!

E.g. which route is more intelligent?

A business person & a philosopher going for a walk in Manhattan



To proceed further (3)

Third, let's be more unpredictable!

What is human-like intelligence?

Human-intelligence is spontaneous, flexible, and/or unpredictable, more or less.

Or even erroneous sometimes.

A possible trick to the Turing Test

might be

to give a same question repeatedly.

To mimic a human

$$\Downarrow$$

Do not always exactly the same action even in a same situation.

"I beg your pardon?"

Intelligent people try a different explanation for an easier understanding

while

others just repeat the same expression, maybe louder.

I couldn't enjoy sushi by a sushi robot!

because it tastes always the same.

Why spontaneous?

We sometimes need spontaneous and unpredictable intelligence rather than efficiency or effectiveness like in case of SONY's AIBO.

It learns excellently and acts differently in different situation but repeats the same action in a same situation.

Sooner or later the owners lose their interest

Our modification

Legg & Hutter's

"an ability to achieve goals in a wide range of environments"

$\Downarrow$

"ability to achieve a goal in an environment"

$+$

"an ability to act differently even in a similar situation"

A measure of similarity

Intelligence in a specific domain

$$\gamma(\pi) = \sum_{\mu \in E} 2^{-K(\mu)} \cdot V_\mu^\pi \qquad \Rightarrow \qquad \gamma(\pi) = 2^{-K(\mu)} \cdot V_\mu^\pi$$

$\Rightarrow$ repeat a run in a same condition to see similarity

$$\gamma(\pi) = \sum_i \frac{2^{-\{\text{COMPLEXITY}\}_i} \cdot \left\{\text{EXPECTED REWARD}\right\}_i}{\left\{\text{SIMILARITY}\right\}_i}$$

Let's summarize

based on Legg & Hutter's definition

$\Downarrow$

but specific, not universal

$\Downarrow$

more reallistic complexity measure, not by Turing Machine.

$\Downarrow$

expect a different action in a same situation.

Is Occam's razor principle really necessary?

Occam's razor plays an inportant role but at the same time we doubt it

Once Kluger wrote in the TIME Magazine

"intelligent individuals are more difficult to learn to know."

⇓

Artificial agents sometimes must pretend to be complex.

⇓

The issue is still open and many things await to be done.

⇓

Let's cooperate!

Dziękuję!