Computational Thinkers: The Emulator Example

(Based on Clark and Grush)

Realism about Computational Thinkers:

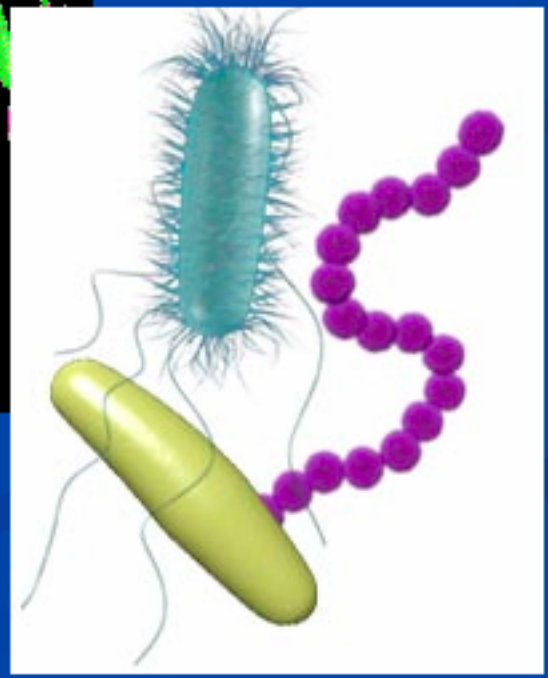
The claim that the human brain and CNS, in at least some of its functioning, **actually IS a computational** device.

Moreover, that it is a computational device at **precisely the descriptive level best suited for understanding the mind**.

Computational thinking, if this is correct, is especially appropriate for the study of the mind because ***the mind really does (in part) work that way*.**

Not so for bacteria, plants, combustion engines…

Claim is that we (and many other creatures) are **Real Computational Agents (RCA's)**



Q/ How do you spot a Real Computational Agent?

Suggestion: It is at least a **necessary** condition for being an RCA that you possess an **inner economy that (really) trades in internal representations.**

RCA's must be RRA's (Real Representation-using Agents)

Sufficient?

(this now nicely accommodates all kinds of computation: analog, quantum, classical, connectionist, etc etc)

Are we RRA's?

Demonstrate:

1.That you have a conception of

internal representation that is **non-trivial**

2.That identifying inner states as representations does **real explanatory work.**

3.That such states, if they exist, figure **deeply in biological cognition**; they are not just some 'tip of the iceberg' phenomenon.

Motor Emulation as a minimal plausible case of Real Representation-using Agency

Skilled Reaching (fast intentional reaching) requires fast proprioceptive feedback…

In fact, **too fast**: 200-500 ms as minimal delay between onset and use of pp info.

Yet many **apparently feedback governed corrections made during first 70 ms of action unfolding**

(see Van der Gron (1988), Grush (1995) and others


celebrate

Very general problem

Eg chemical plants that must control reaction by adding chemicals, but **if you wait for the feedback cues it is too late**

Or bio-reactors that must keep bio-mass in a tank constant…

See Ungar 1990 for lots of examples.

Enter the Emulator (forward model)

A circuit that takes as input:

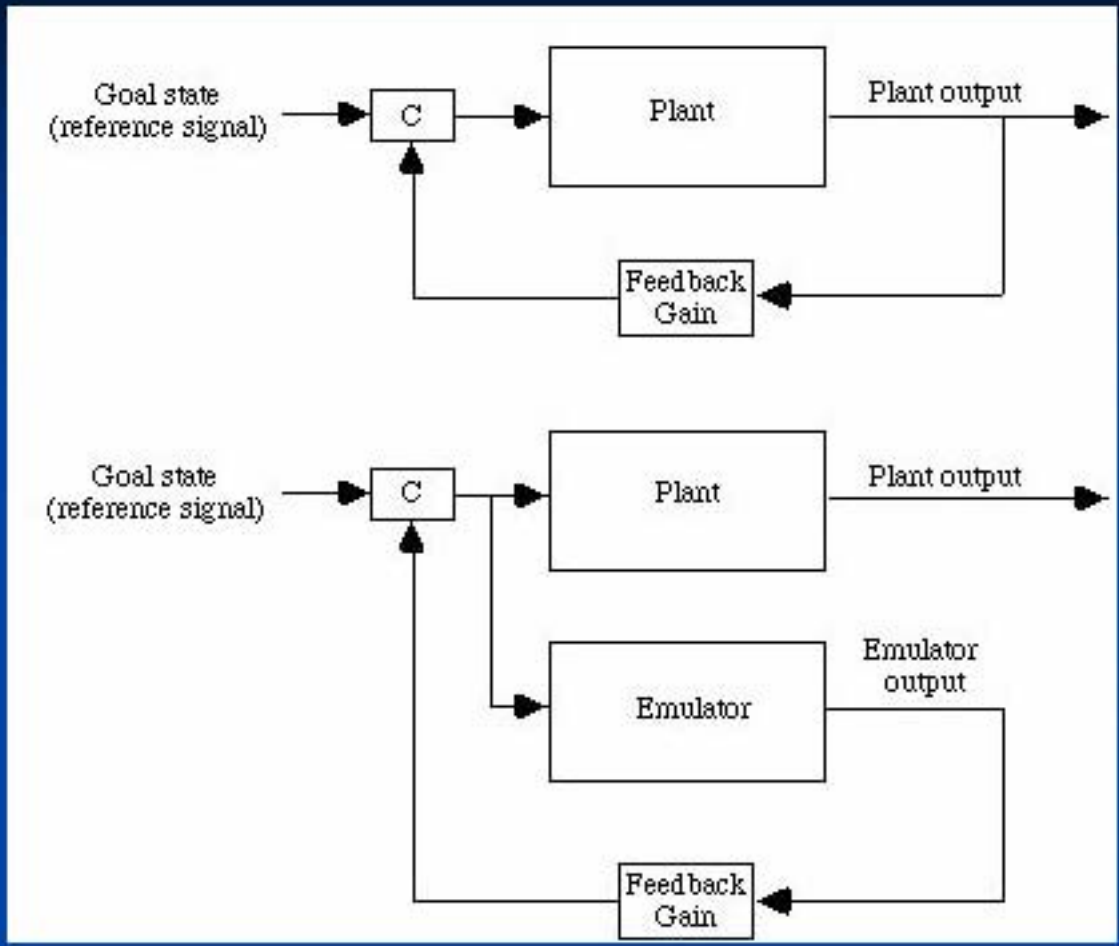
•The **starting state** of a system

•The **current control command**

And gives as output

• a **prediction** of what feedback the system should give at some subsequent point in time

Emulator circuit models the target system, and uses operations on the model to generate **mock or virtual feedback signals**


Goal state
(reference signal)
C
Plant
Plant output
Feedback
Gain
Goal state
(reference signal)
C
Plant
Plant output
Emulator
Emulator
output
Feedback
Gain

In the reaching case:

A copy of current motor command is sent to a circuit whose output is a **prediction of what the sensory feedback ought to be.**

This ‘emulator circuit’ has identifiable states that stand-in for different aspects of the target (larger) circuit, and its overall behaviour **replicates the salient dynamics of the larger system**

Used for **fast error-correction**

Can also cancel sensations arising from **self-motion** (Blakemore et al (1999))

Ito(1984) Kawato et al (1987) Wolpert et al (1998) (2001)

Some neural plausibility for the general idea.

•Some physiological evidence that favours the **cerebellum as a 'Smith Predictor'** (Wolpert et al 1998).

•Cerebellar damage and **reaching oscillations..**

+ simple NN demos by Kawato and others. Developed **units that stood for specific parameters** like elbow angle etc= articulated models.

Smooth reaching: yes

But more too….

Speculation that **running the same kind of circuit offline yields motor imagery useable for planning and reasoning**

Decety et al (1990)

Example: Mel's robot

Generates visual imagery via **emulating its own motor-visual loop**

•Moves around in simulated world populated by 'wire frame shapes'

•Emulator circuit (NN) learns to predict next retinal input from current vis state and current motor command

•Later, uses **same circuit for offline work**, to pan, zoom, and rotate in mental image.

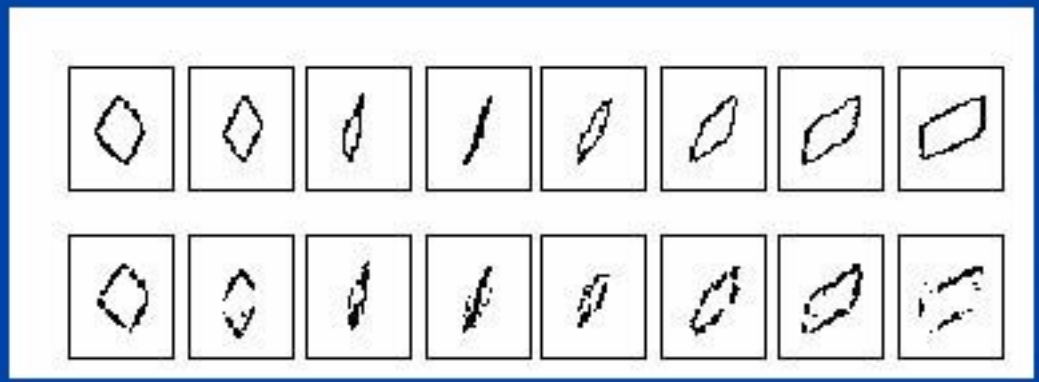
(takes a visual input, inhibits retinal pathway, issues motor commands but turns off actual walking, so **cycles through sequences of object views as if walking around the object**)

See Mel (1986), Grush (2004) p.386

Real and imagined rotations (adapted from Mel (1986)

Top Row= sequence from real vision, moving around a (simulated) wire frame parallelogram

Bottom Row= mental rotation from first view.



Allows learning of motor skills to **continue offline**

Explains why **imagined mental rehearsal** can aid sports skills, as engaging the very same circuits used online

And why **cerebellum** lights up during mental imagery

Nice package:

EM first enhances real-time **online behaviour** (smooth reaching etc)

Then supports **imagery in absence of real environmental input.**

Which could clearly **feed planning and reasoning.** Such systems can try out ideas in imagination rather than in the real world

(Calvin (1996) **"Thinking is movement that has not yet taken place"**).

motor emulation used for imagery/planning = excellent example of **‘offline embodiment’**

“mental structures that originally evolved for perception or action appear to be **co-opted and run ‘off-line’**, decoupled from the physical inputs and outputs that were their original purpose, to assist in thinking and knowing”

(Wilson (2002)) p.633

Soft Continuity

The motor emulator, used offline, is **not a brand new kind of resource. No great evolutionary leap.**

As a representational resource, it remains **closely tied to perceptuo-motor arena and to the bio-dynamics of the system.**

But once in place, it paves the way for a whole new type of functionality viz **model-based deliberation and reasoning**

Upshot/

A genuine divide in the space of adaptive response?

Some creatures remain **trapped in a web of closed-loop interactions** with the very aspects of the world upon which their survival depends.

Other creatures **break the loop**, and are capable of **using stand-ins (internal or external representations)** instead.

These creatures are primed for dreaming, musing, planning….all the Cartesian favourites (see Grush (2003) (2004))

but now with an embodied twist..EM style reps are not a bottleneck impeding real-time success but an efficiency-boosting trick

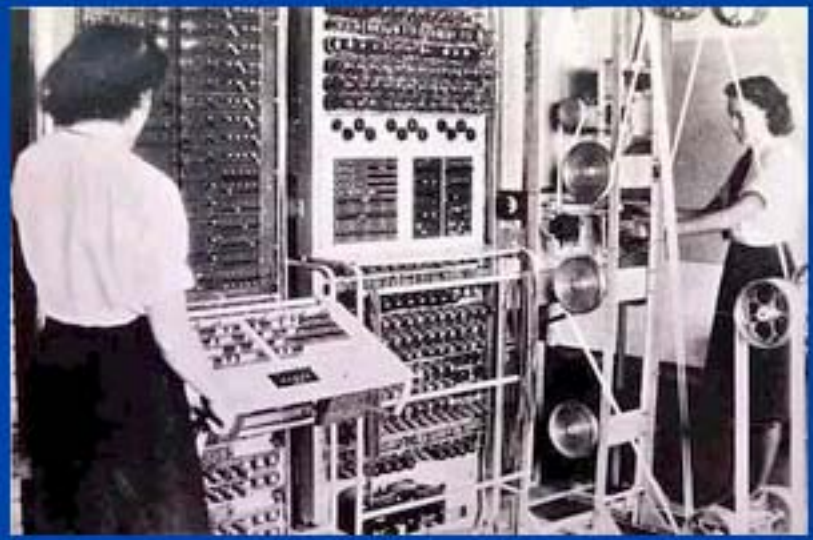
an angle on the cognitive/non-cognitive divide?

“ cognitive agents are exactly those which can selectively couple to either the ‘real’ environment or to an environment model, or emulator, perhaps internally supported, in order to reason about what would happen if certain actions were undertaken with the real environment.”

Grush (1997)

Cognition, the use of representation (internal and external) and real computational agency all go hand in hand

De-bugging the RCA claim.



“These emulator states don’t look like representations to me”

Different in a good way!

Not GOFAI style reps.

Derived rather directly from **resources for perception and action**

Not in some general-purpose code.

Could be **analog.**

But standing-in role is clear. EM role is to cope when guiding environmental signal not available

Shows that **space of RCA’s/ RRA’s is large and liberal.**

*“ Why not just view the emulator circuitry as **just another dynamical system**? Why bother with the representational story? It doesn’t add anything to the understanding you’d get by knowing the mini-loop and maxi-loop dynamics alone”*

No….this is where **computational thinking about real computational thinkers** pays off…

1. The representational glosses help us understand why ***having those very dynamics is valuable*****,** and why they are as they are.

Seeing that unit 3 (in simple demos) represents changes in the angle of the elbow joint explains why unit 3 is connected to unit 2 in the way it is, why it has the tuning curve it does, etc.

2. Representational account also helps **fix the equivalence class of dynamical systems that could fill that specific functional role**

- could use populations of units to code for each parameter
- could use overlapping coding
- could even use a look-up table
- could use more complex dynamical features.

Representation talk directs us to the **functionally salient properties of any system that uses real stand-ins to break the chain of cause and effect.**

3. Invites us to **ask useful questions of the brain/CNS:**

What other circuits does this one **talk to?**

What **might they de doing that needs that kind of information?**

etc

"Ok for toy circuits with simple dynamics. But ***the brain just doesn't work that way "***

Less compelling with emulator-style unpacking on the table. Neurally plausible.

But I suppose it is **logically possible** that it turns out that we somehow **make do with no systems of inner decoupleable stand-ins.**

In which case we would be **representers** (we obviously represent the absent etc) **who don't use internal representations to support that capacity.**

???

*“What, then, is the role of **pure coupling** (all those neat, frugal strategies we lately love so well) in cognition?”*

Those ways of **engaging the world our thoughts are about** are what gives real content to the inner and outer models and representations.

coupling+ offline use = cognition

*"But couldn't there be a **purely online** version of RCA/RRA?"*

Possibly. (see Wheeler (2005))

Need to motivate claim that some purely online-useable states play the role of **standing-in for X** rather than (merely) that of **carrying information about X.**

e.g. a forward model that is not de-coupleable, that always runs just ahead of action.

But the cognitively interesting divide seems to arise where offline imagery and planning is enabled, i.e. when the resource can indeed decouple and run offline…

overall= aiming for a mix of old and new.

> **“computing is a literal description of aspects of cognitive processes” Pylyshyn (1987)**

But **what** gets computed is expected to have deep roots in **perceptuo-motor learning and embodied action.**

And it remains an **open empirical question** just which, if any, aspects of animal performance turn out to **require** real computational and real representational agency.

Clark, A and Grush, R (1999) “Towards a Cognitive Robotics” *Adaptive Behavior* 7: 1: 5-16

Grush, R (2004) “The emulation theory of representation: Motor control, imagery, and perception” *Behavioral and Brain Sciences* 27:377-442

Miall, R.C (2003) “Mirror Neurons and Forward Models” *Neuroreport* 14:16

Wolpert, D, Miall, R.C., and Kawato, M (1998) “Internal models in the cerebellum” *Trends in Cognitive Sciences* 2:9:338-347

Wolpert, D., Ghahramani, Z and Flanagan, J.R (2001) Perspectives and Problems in Motor Learning” *Trends in Cognitive Sciences* 5:11: 487-494

Alternative Carving

Representation where X plays role of standing-in for Y, and is part of some system of stand-ins.
Computation where automatic transitions between representations respects semantics of the stand-ins.
Cognition where there is computation in an affectively valenced (goal-driven, autonomous) system.

Mental lives where such cognitive agents are capable of disengaged or offline reason.

(And this bites much sooner than you might think, with motor-emulation based circuits providing a foot in the evolutionary door for imagery and planning).