Look at the role of:

Bodies

Action

World

Bodies

Key idea: control and information processing are not restricted to the brain/CNC

Instead, **bodily structure and activity** may be exploited, in all manner of unexpected ways

Honda's Asimo

A highly advanced humanoid robot displaying a full 26 degrees of freedom.

But not (or not yet!) exploiting its own embodiment to the full.

Consider **energy efficiency….**

Energy efficiency can be measured via **'specific cost of transport' = the amount of energy required to carry a unit weight a unit distance.**

SCORES (the lower the better: taken from Collins and Ruina (2005) **Asimo: 3.2 Typical Human: 0.2.**

WHY? Because in Asimo "each joint has a motor and control assembly"

ASIMO cannot benefit from the swing of its own legs…**ASIMO's body is just one more problem to be solved…but the body can be part of the solution**

Compare: Passive Dynamic Walkers (PDW's)

No actuation (power) except gravity, and no use of calculated joint angle control at any time!

Yet surprisingly, PDW's are capable (when set on a gentle incline) of **very stable, human-looking walking.**

Q/ How to build on this kind of fluency in a powered walking device?

A/ Rely on a control regime that systematically **pushes, damps and tweaks** a system in which Passive Dynamic effects continue to play a very major role = **control as a gentle nudge to a complex system..**

In this way, a low energy source, a simple control system, and the body (and gravity!) can 'collaborate' to solve the walking problem.

= the power of **co-evolving morphology (shape) and control.**

"Efficient Bipedal Robots Based on Passive-Dynamic Walkers" **S. Collins, A. Ruina, R. Tedrake, M. Wisse *Science* 307, 1082-1085 (2005)**

= a 'new design and control paradigm' (op cit p 1083) for walking robots

‘Robotoddler’ (Russ Tedrake, MIT, 2005)

Learns a **control policy that exploits the passive dynamics of the body.**

change speeds
forward and backward
different terrains

Or consider the robot puppy, called PUPPY

Puppy's **aluminum legs and feet** play an important adaptive role: they induce, as the video shows, small amounts of **slippage** on most surfaces.

Reducing the slippage by adding rubber pads to the feet actually caused the robot to **begin to fall over**!

The subtle slippage was actually playing a stabilizing role, effectively **enabling the robot to rapidly search for a stable way to proceed**

= another example of "making the most of the messiness"

(see Pfeifer and Bongard (2007) pp 96-100, 125-128 for discussion).

First Moral : **control and processing leak into the body…**

Bodily shape (morphology) and bodily bio-mechanics re-configure a wide variety of problems in ways that promote fluidity and efficiency by simplifying the neural commands required to bring about complex behaviours, **effectively delegating aspects of control and processing to the body itself.**

Next: **Action**

It is not just the gross form and bio-mechanics, that may be doing unexpected work, but also the **skilled use of the body in action.**

Key contribution of action concerns the power of what Lungarella and Sporns (2007) call the **active self-structuring of a data flow**

A simple example: BABYBOT (Metta and Fitzpatrick) learns about object boundaries by poking and shoving.

= simple idea of **searching for spread of motion activity**.

BABYBOT moves its arm and it's visual system can detect that motion.

If there is a **sudden spread of the detected motion outwards**, that means that the arm has **encountered, and is now pushing, an object.**

So the BABYBOT's own motor action has now induced an **informative sensorimotor correlation**: the sudden spread of motion **identifies the boundaries of an object.**

Nor is this just a trick for babies:

We are **rampant self-structurers of our own information flows.**

In 'higher cognition' we constantly **sketch, scribble, gesture, and talk to ourselves**, creating structured flows of visual and auditory stimulation that can enhance and guide our own cognitive activity.

An interesting case: the (possible) **role of physical gesture in the process of thought**

A general picture:

At many levels, **self-generated motor activity** acts as a "**complement** to neural information-processing", creating new, whole, **highly complex, systems** in which

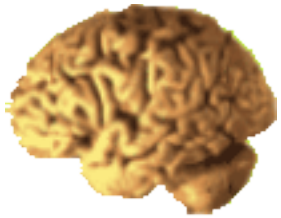
> "'information structuring' by motor activity and 'information processing' by the neural system are continuously linked to each other through sensorimotor loops" Lungarella and Sporns (2005) p.25

Lungarella, M., Sporns, O. (2005) Information self-structuring: key principle for learning and development. Proceedings 2005 IEEE Intern. Conf. Development and Learning, pp. 25-30.

Second Moral: Cognition leaks into whole action-perception loops.

The presence of a self-controlled, acting, sensing body allows an agent to **sculpt her own sensory input streams** in ways that promote learning, reasoning, and efficient problem-solving.

The engine of some forms of cognizing is thus not the naked brain



but a **complex whole involving the brain in concert with the sensing acting body.**

= Brain, + Body…next: World!

An old favorite from Being There: **The (Bluefin) Tuna Puzzle** (work by Triantafyllou brothers at MIT)

The aquatic performances of bluefin tuna **far outpace their basic physical powers**.

They simply **should not be able** to go as **fast** as they do, to **turn so sharply**, to blast off so powerfully, etc.

Too weak by **about a factor of 7.**

Solution? The tuna use **naturally occurring eddies and vortices** (eg where water hits a rock)

And they use their own **tail flaps to actively create** local vortices and pressure gradients **that they then exploit** for rapid start-offs etc

Efficiency way over 100%, tested using a **49 inch anodized aluminium and lycra robot tuna** in a tank at MIT

Now consider our own **artifact-enhanced cognitive processing…**

We use all kinds of **external operations and media, from spreadsheets to iPhones,** to enhance and extend our problem-solving powers.

We write **notes as we think, we draw diagrams** that we ourselves **immediately inspect**

We talk out loud, we gesture while we talk, and we **feel the gestures and hear what we say…**

Just as the Tuna structures its world to promote better swimming, we structure our worlds in ways that – **incrementally**, and at **multiple scales of space and time -** promote **better thinking**.

Exchange between **Richard Feynman** (the Nobel laureate physicist) and the historian **Charles Weiner**

" Weiner once remarked casually that [a batch of notes and sketches] represented "a record of [Feynman's] day-to-day work," and Feynman reacted sharply.

"I actually did the work on the paper," he said.

"Well," Weiner said, "the work was done in your head, but the record of it is still here."

"No, it's **not a *record*, not really. It's *working***. You have to work on paper and this is the paper. Okay?" "

Quoted in *Genius* (Gleick's biography of Feynman)

It is **not** that all the thinking happens inside the head, and the loop out into symbols on a page is just a kind of convenience or a way to avoid forgetting.

Rather, the loops to external media, just like physical gestures, form **part and parcel of an integrated system for thinking.**

(For lots of examples, see Clark (1997) (2003) (2008))

Clark, A (1997) *Being There: Putting Brain, Body and World Together Again* (MIT Press, Camb. MA).

Clark, A (2003 *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence* (Oxford University Press, NY).

Clark, A (2008) *Supersizing the Mind: Action, Embodiment, and Cognitive Extension* (Oxford University Press, NY)

The Naked Brain Fallacy

Giving full credit for intellectual achievement to the biological brain alone, instead of seeing it as **one player on a busy stage** full of props and scaffoldings whose contributions are complex and profound.

Third (and final) Moral:

Cognition leaks **not just into the body, but into the world**, including (especially) the world of external symbol structures, diagrams, etc.

As a result, some of an agent's cognitive processes are run on **new machines** constituted by **combinations of resources spanning brain, body, and world**.

Our filmed session stops about here…rest are just in case of use/interest

Important but here omitted:

The crucial role of **other agents** in the socio-technological matrix.

Considerations concerning **the body and emotion**

Questions concerning the precise role of embodiment and action in **the generation of conscious experience and awareness**

The Story So Far:

To understand real human cognition, we need to take the 3 morals very seriously.

Cognition, control, and processing leak messily into **body, action, and world**!

Overall, we are simply a **lot stranger** than we think

Imagine:

A chess machine that kept **talking to itself** (perhaps very very softly) while it was pondering the next move

Or an expert system that, when asked a question, proceeded to **print out a few sketches** which it carefully **examines using its own cameras,** and then repeatedly **amends** using its own effectors, before issuing a verdict.

Such odd entities would belong, like us, to the space of evolved cognitive engines built to **make the most of body, action, and world.**

Final Q/ How (if at all) shall we understand such systems?

A/ Not easy!

Many effects here depend on **complex non-linear interactions at multiple time-scales** and spanning **multiple levels of organization**

These brain-body-world processes are **multiply hybrid** involving:

neural representations and computations,

bio-mechanical propagations of force and energy,

physical manipulations of **external symbol systems**

all held together by **sensorimotor loops** in which real **timing** is often critical.

And all empoweringly located in **complex material and socio-cultural** settings

Q/ What tools and perspectives do we need to make sense of this?

One promising ‘bottom up’ approach is via **robotics** work governed by what Pfeifer and Bongard (2007) call the '**Principle of Ecological Balance**’

> ” that given a certain task environment there has to be a match between the complexities of the agent's sensory, motor, and neural systems…[and]….that there is a certain **balance or task-distribution between morphology, materials, control, and environment**” Pfeifer and Bongard (2007) p 123

Also, **developmental and 'neurocontructivist' approaches**

In development brain, body and world interact in complex ways that slowly 'grow' minds like our.

Co-ordinated cognitive and bodily growth is an area ripe for future exploration.

See eg Smith, L and Gasser, M (2005) The Development of Embodied Cognition: Six Lesson from Babies *Artificial Life* 11:1:13-30, and the (2007) two volume *Neuroconstructivism* set by Mareschal et al

Open Question

Can there be a **fundamental theory** linking **morphology, perception, action and neural control** in ways that reveal their **co-operative role in the construction and control** of situated intelligent behaviour?

On the Horizon?

A **unified science of the mind** encompassing ecological context, action, timing, bio-mechanics, dynamics, computation and representation.