Towards Acting, Learning, Reasoning “Co-Bots”

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Towards Acting, Learning, Reasoning “Co-Bots”

Co-Worker Co-Inhabitant Co-Explorer

2015 DARPA Disaster zone Challenge (Lot of things to be Done!!!)
Necessity is the mother of invention: The Story of Betty

Alex Kacelnik's Lab, Oxford
Necessity is the mother of invention: The Story of Betty

- **Perception** (Beyond labelling..... Understanding the scene)
- **Inference** (The goal is not Achievable)
- **Memory** (Recall of a specific past learnt experience: playing with Wires, Twigs)
- **Fine Manipulation** (Creating a hook tool and Using it as an extension of its body)
- **Knowledge of Cause-Effect relations** (Pulling the basket with a Hook Tool)
- **Integration**: The Magic glue
The unstructured real world is full of such situations...
A Converging point for many disciplines of research and innovation

http://www.braininitiative.nih.gov/2025/

Neurosciences

- What neural computations take place in the brains of primates, humans when they exhibit cognitive goal oriented behaviors in unstructured environments
- And why and how some of these functions are lost in diverse cognitive disorders (dementia, schizophrenia, ASD)
A Converging point for many disciplines of research and innovation

Intelligent Autonomous Systems

- What cognitive architectures would enable artificial agents to exhibit robust, flexible and goal oriented behaviors in unstructured dynamic environments...
- How does it connect to emerging trends from brain science and can we causally explain loss of cognitive functions (ex: through virtual lesions)
A Converging point for many disciplines of research and innovation

http://www.braininitiative.nih.gov/2025/

http://sparc-robotics.eu/roadmap

http://www.effra.eu/

End User Applications (Society, Economy)

- **Co-Worker** (Productivity of SME, Quick Switchover to new tasks, Customization N=1, Employee health)
- **Co-Inhabitant** (Beyond Vacuum cleaners- Elderly Care, Assistants)
- **Co-Explorer** (Separating humans from direct line of action)
My Personal research landscape.....

“What I cannot build, I do not understand” - Richard Feynman

Co-Bots are invaluable integrating platforms to bridge disciplines...

- Understand Natural cognition (by building one....)
- Develop Cognitive technologies (for diverse end users)

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http://www.effra.eu/
My personal catalogue for future Co-Bots (Co-worker, Co-inhabitant)

In the rest of my talk, I will discuss 3 potential research directions..

- Connecting Action generation/Simulation
- Connecting Cumulative learning vs. Prospective Memory
- Configurable Cognitive architectures

....push the SoA towards next gen Co-Bots
1. Dexterous Actions (and predicting consequences of potential actions)

The dual process of *Generating dexterous actions* and *Predicting potential consequences of ones/others actions* must seamlessly alternate during any goal oriented Co-Botic Behavior.

......That could come for free
Action generation, Prediction and Understanding are closely interlinked.

**Neuroscience**

- Two sides of the same coin?
- Mirror neurons
- Motor Imagery (FMRI)
- Tool Use studies in Animals
- Direct Intercortical simulation of the parietal lobe

**Practical Problems**

- Runtime Configurability
  - To different body-tool chains as task proceeds
  - To different combinations of task constraints
  - Right pose to enable further manipulation
  - Obstacles
    - Internal limits of motion (safety)

Swiftly Learning new motor skills

Imitating to Complementing
Unifying “Action generation, Simulation and Understanding” in Co-Bots

Body as a Configurable middleware

Our Body is a medium to interact with the world (and also simulate potential interactions….)

- Body Schema in the parietal lobe …that is activated in different contexts...
- Body Schema (Internal Body Model) for Cobots?

The Passive Motion Paradigm (PMP)

...Both Real and Imagined actions are realized through a passive “animation” of a ‘plastic and configurable’ internal body model configured runtime based on the intended task/goal..

Theoretical basis

Passive Motion Paradigm: An alternative to Optimal control, Mohan and Morasso, F. Neurorobotics 2011
When Pliers become fingers in the monkey motor system, Rizzolatti et al, PNAS, 2009
A “Configurable, Growing” Internal Body Model for any Co-bot

Assembled on the Fly

Like electrical circuits
(Two kind of nodes: Force and Position, two types of connecting links Geometric and Elastic)

Three step process

- Configure
- Animate (couple to the goal: Attractor)
- Use (Generate motor commands, or perform forward simulation)

Passive Motion Paradigm: An alternative to Optimal control, Mohan and Morasso, F. Neurorobotics 2011
When Pliers become fingers in the monkey motor system, Rizzolatti et al, PNAS, 2009
Getting ahead; Forward models and their place in cognitive architecture, Pickering and Clark, Trends in Cog Sci, 2014
A “Configurable, Growing” Body schema for any Co-bot

Assembled on the Fly

Action Generation

Passive Motion Paradigm: An alternative to Optimal control, Mohan and Morasso, F.Neurorobotics 2011
When Pliers become fingers in the monkey motor system, Rizzolatti et al, PNAS, 2009
Getting ahead; Forward models and their place in cognitive architecture, Pickering and Clark, Trends in Cog Sci, 2014
Learning the Internal body model (end expanding it to coupled tools)

Both the Internal Body Model and extension to diverse tools can be learnt by any robot (combining exploration and imitation)

Real and imagined actions can go hand in hand

Real and Imagined actions can alternate, yet use the same computational middleware: Activation of the task oriented internal Body model

User Goal
Assemble Fuse Box

Recap
- Runtime Assembly
- Learning
- Generation-Simulation

Generate-Simulate-Simulate Other’s Actions (By analogy)

Andy Clark (2016), Embodied Prediction
Mohan Et al (2016), Towards a learnt body schema for dexterous coordination of action in humanoid and industrial robots, Autonomous robots
Generate-Simulate-Simulate Other’s Actions

Spin Offs + Ongoing extensions

Action Language Coupling
(in collaboration with Plymouth, Hertfordshire, Bielefeld)

Other’s Action Understanding
(in collaboration with Imperial college, INSERM, Sheffield)

Industrial Assembly
(in collaboration with Profactor, FORTH, Kings College)

Whole body synergy formation under constraints
2. Memory for Co-Bots: To flexibly Connect “Past, Present and Future”

It's a poor sort of memory that works only backwards
White Queen to Alice (Lewis Carroll, 1871)

Cognitive systems learn cumulatively - On the job

Memory is not a passive storage device, but rather an active integrative mechanism to connect-

- Past Experiences
- Present Context
- Future Plans/Goals
2. Memory for Co-Bots: Machine learning to Humanlike learning

Learning on the Job
Learning- Empower cognitive systems to learn different things, by different ways and different times
- Motor Skills
- Cause-Effect Relations

Learning Steams
- Imitation
- Interaction + Past experience
- Language based

Biomimetic Memory Framework
-Use past experiences generatively to plan goal oriented behaviors
-Discovery of the default mode network in the brain

2. Memory for Co-Bots: One possible Implementation

Robot Episodic Memory structure for cumulative Encoding of experiences
- 1000 neurons: arranged as a 50x20 sheet, $10^6$ connections
- An experience is a temporal sequence of actions, objects, rewards, body state
- One shot learning
- Experiences can emerge from exploration, user demo, language based instruction

Simple Example: Encoding experience (One shot learning)

Roboearth.eu, robohow.eu, vishwanathanmohan.com
2. Memory for Co-Bots: Remembering to Inferring

Robot Episodic Memory Structure and Encoding of experiences
- 1000 neurons: arranged as a 50×20 sheet, $10^6$ connections
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Simple Example: Multimodal Recall from partial cue in future
2. Memory for Co-Bots: Remembering to Inferring

User: Assemble Fuse Box

User: Assemble Fuse Box (Impossible Goal)

Memories are transferrable beyond embodiments

Fuse box assembly with unexpected intervention, monitoring, reasoning in industrial work cell (Co-Bot Working with an uncooperative human)

Mixed Assembly
Goals are inferred from environmental cues

roboearth.eu, robohow.eu, vishwanathanmohan.com
3. Plug and Play Cognitive Architectures: Big Picture

Gigabit Ethernet (with tcp, udp, multicast traffic)

Onboard PC104 (basic sensory motor processing)

Shuttle PCs (Windows/Linux) (Fundamental processes: PMP, Basic Visual analysis)

Blade Cluster (Linux) (Heavy and continuous computations: vision, reasoning, GUI's etc)

Basic Visual perception
- Color Perception
  - Color An
- Shape Perception
  - Shape An

Advanced Visual perception
- 3D reconstruction
- I-Color and shape analysis
  - O: Where are they

Event driven SM processing
- "Small Worlds" Concepts & OPC
  - Observer
    - 1: What, where what can be done

Observer Executive
- 24: /BodySchemaSim.io
- 25: /GraspCtrl.io
- 26: SmallWorldsOPC/io

User/Teacher interface
- 1: Issue goals
- 2: Reward/Penitalize
- 3: GUI's (what's happening)

Event driven Action generation
- PMP: Body schema
  - 28: LeftArm
  - 29: RightArm

iCub Grasp / Affordance module
- 28: LeftArm
- 29: RightArm

Episodic memory and learning
- 38: /memory
- 39: /memory/memories

Episode driven reasoning, learning & forgetting
- 44: /Hub/Top_Down
- 42: /memory/memories

CZECH TECHNICAL UNIVERSITY IN PRAGUE
KING'S COLLEGE LONDON
PROFACTOR
NOVOCAPTIS
FORTH
3. Plug and Play Cognitive Architectures (Last 4 Years of Engagement)

Basic Assembly on Industrial Platform (Perception-Action Loop)

Multirobot Assembly (Perception-Action - Spatial reasoning Loop)

Recovery from Failures (Perception-Action - Spatial reasoning Loop - Top down monitoring)

Robot Cooperation (Perception-Action - Spatial reasoning Loop - Top down monitoring - Internal model based Simulation)

Quick Switchover to new tasks (Perception-Action - Spatial reasoning Loop - Top down monitoring - Internal Simulation - Online learning)

Mixed assembly (Goals are triggered by the environment)

Comparison with Industrial Benchmark system

<table>
<thead>
<tr>
<th>Demonstration Scenario</th>
<th>DARWIN Cognitive System (Demo specific success rate)</th>
<th>DARWIN Benchmark system (Demo specific success rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>31 seconds</td>
<td>20.9 seconds</td>
</tr>
<tr>
<td>1.2</td>
<td>90%</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>3.1</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>3.2</td>
<td>94%</td>
<td>95%</td>
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<tr>
<td>4</td>
<td>88%</td>
<td>86%</td>
</tr>
<tr>
<td>5</td>
<td>15 minutes</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>6</td>
<td>67% (TSR 80%)</td>
<td>64% (TSR 40%)</td>
</tr>
</tbody>
</table>

Co-Botics is about making learning, reasoning robots that can do much more!
Brain: Just like a big elephant problem

Data to Useful engineering Principles

Need an Integrative approach

Co-Bots are such Integrative platforms
Our quest to understand brain function and designing artificial systems exhibiting cognitive behaviors is at a crucial juncture.

Research Labs and Research led education are fundamental enablers in this direction (QUB Vision 2020).

Concluding message from Charlie Chaplin’s Eating Machine!!!!!
Generate dexterous Actions (and predict consequences of potential actions of oneself and others)

Perception (beyond labelling and rather inferring what one can do)

Learning on the Job (Green, Fast and Cumulatively)

Memory (not passive storage element, but actively connecting past with the present context and possible future)

Configurable “plug and play” cognitive architectures (use a robot like a smart phone)

Domain agnostic, partially embodiment agnostic and strongly brain guided

Future of Co-Bots: Some take home points

My personal roadmap
A pictorial Recap!! (Art is a lie to realize the truth ...Picasso)
Thank You + ?????

Further Info + Contact + Software → www.vishwanathanmohan.com