FROM THIRSTY CROWS TO COGNITIVE ROBOTS

Vishwanathan Mohan (University Of Essex)
February 14th 2018, Tiptree tea room @ Minories
THANKS FOR BEING HERE ON SUCH A LOVE-LY DAY.....AND...

SO YOU ARE ALL IN THE GOOD BOOKS OF THE ROBOTS !!!!
NO EQUATIONS OR ALGORITHMS!
Mostly pictures, videos hopefully interactive!!
(sometimes, you need to guess what the picture means)
OUTLINE OF TODAY'S TALK...
THIRSTY CROW- WHY???

Creativity & Innovation

WE ARE ALL CURIOUS PEOPLE THROWING PEBBLES INTO WATER....
Thirsty Crow of Aesop's Fable in Action

Corvids, Monkeys, Infants...

- Heavy vs. Light
- Sinking vs. Floating
- Sand vs. Water
- Many other cases

Nicola Clayton’s Lab, Cambridge
https://www.psychol.cam.ac.uk/ccl
EVEN MORE FASCINATING IS THE STORY OF BETTY....
NECESSITY IS THE MOTHER OF INVENTION: THE STORY OF BETTY

A SITUATION NEVER SEEN, EXPERIENCED

DINNER

WIRE

ONE YEAR BACK, BETTY HAD EXPERIENCES OF PLAYING WITH FLEXIBLE PLASTIC WIRES.....

ALEX KACELNIK'S LAB, OXFORD
NECESSITY IS THE MOTHER OF INVENTION: THE STORY OF BETTY
IF BETTY WAS A ROBOT INSTEAD ??

- **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**
BETTY HAD A BRAIN .......

ITS FUN!!
AND
ITS ALSO IMPORTANT!!!

• 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...

So it will be for future co-bots

"Connecting the dots"
Steve Jobs
A CONVERGING POINT FOR MANY DISCIPLINES, ROADMAPS

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

http://sparc-robotics.eu/roadmap
New Robot Era 2030

http://www.effra.eu/

CO-BOTS ARE INVALUABLE INTEGRATING PLATFORMS TO BRIDGE DISCIPLINES...

- UNDERSTAND NATURAL COGNITION (BY BUILDING ONE....)
- DEVELOP COGNITIVE TECHNOLOGIES (DIVERSE END USERS)
What I cannot create,
I do not understand.

Why? (cont.): 
To learn "Bethe,
2.0 Hall"
Accept Talk
New Line

Caltech Archive

\[ f = (1 - \alpha) / \alpha \]

\[ g = (\alpha^2 - 1) \]

\[ \alpha = 1 / \alpha \]
While trying to make robots act, learn and reason intelligently, we engineers are solving the same problem that the brain solves...to make ourselves “act, learn and reason” intelligently.
Co-bots of the future...will have to:

- Act (and anticipate consequences..)
- Learn (on the job- cumulatively)
- Brainlike memory- remember and infer
- Social intelligence
- Safe, reliable, real-time
ACTION SYSTEM- HUMANS VS. ROBOTS

Reach/Grasp, Pick, Place—Effortless

DARPA Disaster Zone challenge (2015)

HUMANLIKE DEXTERTITY WHILE OPERATING IN UNSTUCTURED SETUPS
WHY IS THE PROBLEM DIFFICULT?

• INFINITE SOLUTIONS
• MULTIPLE TASK-CONSTRAINTS
  (UNDERSPECIFIED)
• COMPLEX INTEGRATION OF VISION,
  TOUCH, FORCE, PROPRIOCEPTION
• SOFT, DEFORMABLE, PERISHABLE OBJECTS

(WITH TIPTREE FARMS)

• LABOR AVAILABILITY
• HEALTH AND SAFETY
• PRODUCTIVITY
• 1/3RD OF THE PRODUCTION COST

AMAZON PICKING CHALLENGE 2017
https://www.amazonrobotics.com/#/roboticschallenge

ROBOCUP AT WORK (EU)
http://rockinrobotchallenge.eu/work.php
ACTION GENERATION, IMAGINATION AND UNDERSTANDING SHARE CORTICAL NETWORKS IN THE BRAIN
Generating dexterous actions and imagining/anticipating consequence's of potential actions of oneself and other are two sides of the same coin.

Robots
A brain inspired action generation/imagination system for cognitive robots (2006-)

The metaphor

Nina: I am perfect.....
Tomas Leroy: Perfection is not to be in absolute control but to let go...

The black swan (Aronofsky 2011)
A BRAIN INSPIRED ACTION GENERATION/IMAGINATION SYSTEM FOR COGNITIVE ROBOTS (2006-)

- **Learn** an Internal model of the body (and use it to Generate/Predict actions)
- **Even real movement is like a simulation**
A BRAIN INSPIRED ACTION GENERATION/IMAGINATION SYSTEM FOR COGNITIVE ROBOTS (2006-)

- Learn an Internal model of the body (and use it to Generate/Predict actions)
- EVEN REAL MOVEMENT IS LIKE A SIMULATION

ADVANTAGES

- Learning..
- Body/Body+Tools networks (configured on the fly)
- Computationally Simple
- Same system is used to both generate and predict actions
A BRAIN INSPIRED ACTION GENERATION/IMAGINATION SYSTEM FOR COGNITIVE ROBOTS (2006-)

Infer how the environment might change as a result of one's actions, i.e., pushing the fuse box and prediction of its consequences.

Real actions 1-4 executed by the robot to realize the assembly goal.

Internal simulations 1-3 leading to the inference that the Goal is Undoable, given the circumstances (F/I model for reaching).

ACTION GENERATION, PREDICTION SEEMLESSLY ALTERNATE DURING ANY GOAL DIRECTED BEHAVIOUR/ SOCIAL INTERACTION.
SPIN OFFS + ONGOING EXTENSIONS

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

“Lick, Pick, Kick”
“Cut an Apple, Cut a Cake”

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

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

Whole body coordination under diverse Perceptual, Motor and Cognitive constraints (US Army)

AgroTech- Pick and Pack (Tiptree farms)

Subsea cleaning of Oil and Gas pipelines using autonomous robots (TubeTech Inc)
Generate-Simulate-Simulate Other’s Actions

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
Rizzolatii et al (2009), When pliers become fingers in the monkey motor cortex, PNAS
It's a poor sort of memory that works only backwards...

White Queen to Alice (Lewis Carroll, 1871)
MEMORY IS NOT A PASSIVE STORAGE DEVICE BUT AN ACTIVE INTEGRATIVE MECHANISM TO CONNECT
• PAST EXPERIENCES
• PRESENT CONTEXT
• FUTURE CONSEQUENCES
Cognitive systems learn cumulatively: Learning, Remembering and Goal Directed Prospection go hand in hand........
NOT A ONE TRICK PONY- MACHINE LEARNING VS. 'HUMANLIKE LEARNING'

We learn for fun too!!!
BRAINLIKE MEMORY FOR COGNITIVE ROBOTS...

ITS REALLY A SMALL WORLD!

DO OBJECTS REALLY MATTER?

We also know that the brain is organized as a Small World network with Clusters and Hubs.

DEFAULT MODE NETWORK
RECALLING THE PAST AND SIMULATING THE FUTURE

RATS
CROWS
MONKEYS
HUMANS
Growing Episodic Memory for Co-Bots: One possible Implementation

- 1000 neurons: arranged as a 50x20 sheet, $10^6$ connections (like a Blank Page)
- An experience is a temporal sequence of actions, objects, rewards, body state
- One shot LEARNING (Hebbian)
- Possible Learning streams: Exploration, User Demo, Language based instruction

Simple Example: Encoding experience (One shot learning)
Memory for Co-Bots: Central Contributions

MULTIMODAL RECALL (BASED ON PARTIAL CUES FROM THE ENVIRONMENT)

**MULTIMODAL RECALL (BASED ON PARTIAL CUES FROM THE ENVIRONMENT)**

**OBSERVED ACTIONS OF OTHERS ARE ALSO PARTIAL CUES...**

**INFERRING THE GOAL AND COMPLEMENTING THE USER**

GOAL DIRECTED **REASONING** IS SIMILAR TO **NAVIGATION** (BUT IN TIME THROUGH MEMORIES)
CONNECTING THE DOTS OF EXPERIENCES......

Memory for Co-Bots: Central Contributions, Predictions

**Goal Directed Reasoning is similar to Navigation (but in time through memories)**

Connecting the Dots of Experiences......

Multiple remembered experiences are combined to generate novel behaviors.....

GOAL DIRECTED **REASONING** IS SIMILAR TO **NAVIGATION** (BUT IN **TIME THROUGH MEMORIES**) 

**THIS IS COOL BECAUSE....**

BUT ART IS A LIE THAT SPEAKS THE TRUTH!
ROBOT MEMORY- FORGETTING AND SENSE-2-COMMONSENSE
Memory Consolidation: Comparing Remembered Past with Present

Affordance: From “Object Action” to “Property-Action”

A Thirsty Crow

Four Simple Learning Rules

<table>
<thead>
<tr>
<th>Rule</th>
<th>Δ Property (in property-specific maps)</th>
<th>Δ Contradiction (between expected and observed behavior: top-down vs bottom-up)</th>
<th>Update in connectivity strength (between associated property-specific maps and object hub)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elimination</td>
<td>✓</td>
<td>✗</td>
<td>§</td>
</tr>
<tr>
<td>Growth</td>
<td>✓</td>
<td>✓</td>
<td>§</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>✗</td>
<td>✓</td>
<td>§</td>
</tr>
<tr>
<td>Status Quo</td>
<td>✗</td>
<td>✗</td>
<td>§</td>
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Error = Volume of water displaced as
| Predicted by iCub – Calculated using Archimedes’ principle |

- Order A
- Order B
- Order C
- Order D

Time / Number of new experiences

Error in Prediction (in cm^3)
AND SUCH ROBOT MEMORIES ARE TRANSFERABLE.....TO OTHER ROBOTS
AND SUCH MEMORIES ARE TRANSFERABLE....BEYOND EMBODIMENTS

roboearth.eu, robohow.eu, vishwanathanmohan.com
DARWIN COGNITIVE
FRAMEWORK

Continuously streaming
Body

Partially event Driven
Basic Perception
Basic learning

Advanced Perception
Concepts
Semantic memory
Procedural memory

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)

Event driven Action
Advanced learning, Abstraction, Forgetting

Episodic Memory

Fully Event Driven
Cognition
Monitoring

User / Teacher interface
Goals
Rewards
Demos

User / Teacher

DOMIAN AGNOSTIC
PARTIALLY EMBODIMENT AGNOSTIC
GROWING/LEARNING
PLUG AND PLAY

YARP NETWORK

Dr. Trusso
Assemble
Robot
Working with embodied INelligence
DARWIN COGNITIVE FRAMEWORK

- VISUALIZING WHAT IS HAPPENING
- VIRTUAL LESIONS (DISORDERS OF COGNITION)

DOMAIN AGNOSTIC
PARTIALLY EMBODIMENT AGNOSTIC
GROWING/LEARNING
PLUG AND PLAY
Connecting to the End User (Gradual porting of the Architecture)

- **Basic Assembly on Industrial Platform** (Peception-Action Loop)
- **Multirobot Assembly** (Peception-Action -Spatial reasoning Loop)
- **Recovery from Failures** (Peception-Action -Spatial reasoning Loop-Top down monitoring)

- **Robot Cooperation** (Peception-Action -Spatial reasoning Loop-Top down monitoring-Internal model based Simulation)
- **Quick Switchover to new tasks** (Peception-Action -Spatial reasoning Loop-Top down monitoring-Internal Simulation-Online learning)
- **Mixed assembly** (Goals are triggered by the environment)
- **Comaprison with Industrial Benchmark system**

Co-Botics is about making learning, reasoning robots that can do much more!
Connecting to the End User (Gradual porting of the Architecture)

- Robotic companions in hospitals, care homes (3 hospitals in the region)
- One fully funded PhD position just advertised...

Co-Botics is about making learning, reasoning robots that can do much more!
Connecting to the End User (Gradual porting of the Architecture)

- ROBOTIC COMPANIONS IN HOSPITALS, CARE HOMES (3 HOSPITALS IN THE REGION)
- ONE FULLY FUNDED PHD POSITION JUST ADVERTISED...

Co-Botics is about making learning, reasoning robots that can do much more!
Going back to Neurosciences (Why and Why Now?)
Going back to Neurosciences (Why and Why Now?)

Brain: Just like a big elephant problem

Data to Useful engineering Principles

Need an Integrative approach

Co-Bots are such Integrative platforms
Going Back to History of Science

DNA - Interdisciplinary efforts

“We’ll start with the soup again.”

Our quest to understand brain function and designing artificial systems exhibiting cognitive behaviors is at a crucial juncture

Concluding message from Charlie Chaplin's Eating Machine!!!!!
Thank You + ?????

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