Emergence of the Sentient Web and the revolutionary impact of Cognitive AI

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Future Directions Session
OGC Technical Committee Event*

* see: http://ogcmeet.org/events/2003tc/
Where we are now …

• RDF is a successful framework for representing data and metadata
  • Large suite of standards including SPARQL, OWL, SHACL, Turtle, JSON-LD, ...
  • Plenty of work on ontologies and wide deployment of schema.org vocabs

• Growing industry interest in Labelled Property Graphs (LPG)
  • Easier to work with n-ary relationships
  • No need for reification to annotate graph edges

• LPG is weak on interoperability across different vendors
  • ISO work on LPG extensions to SQL and new work item on GQL query language

• Easier RDF initiative seeking to make semantic technologies based upon RDF easier for the average developer (the middle 33%)
Chunks as an amalgam of RDF and LPG

Inspired by work in Cognitive Psychology and Neuroscience

• Chunks as collection of properties whose values reference other chunks
  • Values are names, numbers, true, false, quoted string literals, or comma separated lists of values
  • Context chains for handling multiple perspectives
  • Simple mapping to RDF for integration with existing systems

• Simple syntax – simpler than JSON-LD

friend f34 {
  name Joan
}
friend {
  name Jenny
  likes f34
}

• Where friend is a chunk type, f34 is a chunk identifier, name and likes are property names, Joan and Jenny are also names.

likes f34 signifies that Jenny likes Joan via the link to the chunk for Joan.

• Missing chunk identifiers are automatically assigned when inserting a chunk into a graph

• Uses line breaks as punctuation

kindof {
  subject dog
  object mammal
}
kindof {
  subject cat
  object mammal
}
is equivalent to

dog kindof mammal
cat kindof mammal

Chunks correspond to activation across bundles of nerve fibres, see Chris Eliasmith’s work on semantic pointers
Blending Symbols with Statistics

- Traditional approaches to handling data struggle in respect to the uncertainty, incompleteness and inconsistency commonly found in real-world situations
  - This exacerbates the cost for preparing and cleaning data prior to analysis, a major bugbear for data science
- Remembering what’s important based upon prior knowledge and past experience
  - Data recall is like web search engines that determine which matches are most likely to be useful as distinct to all the rest
- Machine learning with relatively few examples, just like humans!
  - Unlike Deep Learning which starts from scratch, requiring huge numbers of training examples, and lacks salience, making it brittle and easy to fool
- Forms of reasoning that rely on statistical considerations
  - e.g. abduction which seeks explanations of observed behaviours
  - Graph manipulation rather than formal semantics
  - Logic → thinking intertwined with feelings
- Relational databases are now giving way to graph databases, and will in turn give way to cognitive databases that combine graph data, statistics, rules and graph algorithms
- **Sentient Web**: combination of the IoT and Cognition to enable ecosystems of smart services
  - Sensing + reasoning federated across the Web
Cognitive AI

• In short, Artificial Intelligence inspired by advances in the cognitive sciences
• In other words, we would do well to borrow from nature when it comes to building AI systems
• We can mimic nature at a functional level using conventional computer technology without having to implement cognitive agents in terms of artificial neurons
• There are many potential applications of cognitive agents for human-machine collaboration
The Brain has evolved over hundreds of millions of years.
**BRAIN SIZE AND NEURON COUNT**

Cerebral cortex mass and neuron count for various mammals.

![Brain sizes and neuron counts](Image)

<table>
<thead>
<tr>
<th>Species</th>
<th>Mass</th>
<th>Neuron Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capybara</td>
<td>48.2 g</td>
<td>0.3 billion</td>
</tr>
<tr>
<td>Rhesus Macaque</td>
<td>69.8 g</td>
<td>1.71 billion</td>
</tr>
<tr>
<td>Western Gorilla</td>
<td>377 g</td>
<td>9.1 billion</td>
</tr>
<tr>
<td>Human</td>
<td>1232 g</td>
<td>16.3 billion</td>
</tr>
<tr>
<td>African Bush Elephant</td>
<td>2848 g</td>
<td>5.59 billion</td>
</tr>
</tbody>
</table>

Note: across species, the cortex has under a third of the number of neurons in the cerebellum.
Brain function – many specialized areas

**FRONTAL LOBE**
- ability to concentrate, judgement, analysis, problem solving, plan, personality etc

**PARietal LOBE**
- integrate information from several senses, including speech, pain and touch sensation etc

**TEMPORAL LOBE**
- deals with high level visual processing (faces & scenes)

**OCCIPITAL LOBE**
- visual processing center of the brain, mostly what is referred to as a "visual cortex"

**CEREBELLUM**
- perform some cognitive function, like attention and language. Also controls the voluntary movement

**BRAIN STEM**
- serves as brain's warning system and sets alertness

*Courtesy of Human brain facts*
Cognitive AI Architecture
with multiple cognitive circuits

Cortex
Multiple specialised graph databases + algorithms

Sensory system
Perception
Pipelined processing

Limbic system
Emotion
Feed forward network

Basal Ganglia
Cognition
Sequential rule engine

Cerebellum
Action
Real-time parallel control
The human cortex is functionally equivalent to a set of specialised cognitive databases and associated algorithms.

A cognitive database holds chunks: collections of properties that include references to other chunks.

Chunks are associated with statistical information reflecting prior knowledge and past experience.

Cognitive databases have the potential to store vast amounts of information similar to the human cortex.

Cognitive databases can be local or remote, and shared with multiple cognitive agents, subject to access control policies.

Memory retrieval fits Web architecture.

- Remote invocation of graph algorithms in request/response pattern rather like HTTP.
- Analogous to Web search engines where results are computed based upon what is likely to be most relevant to the user – impractical and inappropriate to try to return complete set of matches.

Cognitive databases support a variety of algorithms that are executed local to the data.

- Scalable to handling Big Data.

The algorithms depend on the intended function of the database, e.g.

- Basic storage and recall.
- Specialised algorithms for natural language, spatial and temporal reasoning.
- Algorithms for data analytics.
Sensory Perception

• Our senses
  • Smell, taste, touch, pain, heat, sound, vision, ...
  • Perception creates short lived representations in the cortex
  • The cortex can likewise direct sensory processing as needed

• Touch and pain are mapped to a homuncular model of our bodies

• Proprioception – sense of self-movement and body position
  • Limbs, joints, muscle load
  • Vestibular system (inner ear)

• Sound is fleeting
  • Processing word by word
  • Emotional cues

• Vision is much more complex
  • Two eyes for stereo depth perception
  • Each eye: high resolution narrow angle + low resolution wide angle
  • Saccades as eyes swivel to scan areas of interest
  • Good at recognizing many different kinds of things, including their structures & behaviours
  • Context determines what is interesting and relevant
  • Alerts signal relevant things in field of view
  • Focus directs attention to specific things
  • Reinforcement learning from experience

Implementation as pipelined neural networks
Emotions, Feelings and Moods

Towards strong empathic* AI

• **Cortico-Limbic system**
  - Important from an evolutionary perspective
    - Avoidance of harm, fear of predators, interest in prey, courtship, care of young
  - Enhanced for living in social groups
    - Emotional intelligence – awareness of what others are feeling, and signalling your own feelings
  - Emotions are associated with a feeling and something they apply to
    - Valence describes whether feeling is positive, neutral or negative
    - Arousal describes whether feeling is calming or exciting
    - Moods are long lasting emotions that lack the cognitive element

• Triggered by
  - Perception (e.g. seeing a predator), reasoning about situations, recall of emotive memories

• Effects
  - Instinctive behaviours and how these are regulated by cognitive control
  - Prioritising what you are thinking about and what feels important
  - Influences on recall, new memories, reinforcement of existing memories and reinforcement learning of behaviours

• Fast and instinctive vs slow and deliberate
  - Rapid instinctive appraisal and response, avoiding the delay incurred with conscious thought, but subject to errors of judgement due to lack of thought
  - Functional implementation as a feed-forward classification network

* empathic: /ɛmˈpaθɪk/ adjective – showing an ability to understand and share the feelings of another
Cognition and Conscious Thought

• **Cortico basal-ganglia circuit**
  • The centre of conscious thought

• **Symbolic (graphs) + sub-symbolic (statistics)**
  • Chunk based symbolic representation of concepts and relationships
  • Statistical weights reflecting prior knowledge and past experience

• Rule engine connected to many parts of the cortex
  • Connections via buffers that hold single chunks
  • Rules represent reasoning & procedural knowledge
  • Learned from experience (hierarchical reinforcement learning)

• Sequential application of rules to cognitive buffers
  • Approximately every 50 mS

• Parallel processes for graph algorithms
  • Recall of memories
  • Selection of rules

• Autobiographical and episodic memories
• Reasoning at multiple levels of abstraction
Action

- **Cortico cerebellar circuit**
- Handles actions devolved to it by conscious thought
- Real-time control with parallel processing
- Contains more than three times the number of neurons in the cortex*
- Cerebellum acts as flight controller managing activation of myriad sets of muscles in coordination with perceptual input from the cortex
- Offloads processing from cortico basal-ganglia circuit thereby enabling higher level thought whilst actions are underway
- Performance degrades when conscious thought diverts visual attention, starving cerebellum of visual feedback
- Learning through experience, starting with conscious thought
- Implemented as suite of real-time continuous state machines
- Examples: talking, walking and playing the piano

* The human cerebellum contains 70 billion nerves vs 20 billion for the cerebral cortex, see Suzana Herculano-Houzel, 2010
Application to Autonomous Vehicles

- **Cognitive AI demo that runs in a web page**
  - Mapping data for a small town was exported from Open Street Maps as XML (3.1MB) and transformed into chunks (637 KB)
    - Points with latitude & longitude
    - Paths as sequence of points
    - Roads as collections of paths
- **Graph algorithm for spatial indexing** – constructs corresponding Quad Tree index with chunks
- **Graph algorithm for route planning** ("A star")
- **Visual model raises alerts that signal**
  - When approaching junction
  - When entering & leaving junction
  - When arriving to the destination
- **Cognitive rules as chunks for ease of learning**
  - Start and stop turn indicator lights
  - Initiate braking or accelerating
  - Initiate lane tracking and turning
- **Functional model of cortico-cerebellar circuit** provides real-time control of brakes, acceleration and steering, as initiated by cognitive rules

```prolog
# retrieve turn
alert {@module goal; kind turn; turn ?id }
=>
    turn {@module goal; @do recall; @id ?id}

# prepare for turn
turn {@module goal; @id ?id; signal ?direction} =>
    action {@module car; @do brake; turn ?id},
    action {@module car; @do signal; signal ?direction},
    alert {@module goal; @do clear}

# start turn
alert {@module goal; kind stop} =>
    action {@module car; @do steer; mode turn},
    action {@module car; @do cruise; speed 20},
    alert {@module goal; @do clear}
```
Application to Smart factories

- Cognitive AI demo that runs in a web page
- Live simulation of bottling plant with robot, conveyor belts, filling and capping stations
- Real-time control by a cognitive agent

```cog
# add bottle when belt1 has space and wait afresh
space {thing belt1} =>
action {@do addBottle; thing belt1},
space {@do wait; thing belt1; space 30}

# add box when belt2 has space and wait afresh
space {thing belt2} =>
action {@do addBox; thing belt2},
action {@do stop; thing belt2},
space {@do wait; thing belt2; space 95}

# stop belt when it is full and move arm
full {thing belt1} =>
action {@do stop; thing belt1},
action {@do move; x -120; y -75; angle -180; gap 40; step 1}
```

Log:

```log
executed rule _:117 step
set goal to: after _:54 {step 1}
executed rule _:27 move
set goal to: after _:55 {step 2}
executed rule _:30 grasp
set goal to: after _:56 {step 3}
starting belt1
wait on filled
executed rule _:34 start
```
W3C Cognitive AI Community Group

See: https://www.w3.org/community/cogai/, https://github.com/w3c/cogai

• Participation is open to all, free of charge
• Focus on demonstrating the potential of Cognitive AI
  • A roadmap for developing AI that is strong, empathic and trustworthy
• Collaboration on defining use cases, requirements and datasets for use in demonstrators
  • https://github.com/w3c/cogai/tree/master/demos
• Work on open source implementations and scaling experiments
• Work on identifying and analysing application areas, e.g.
  • Helping non-programmers to work with data (worth $21B by 2022 according to Forester)
  • Cognitive agents in support of customer services (worth $5.6B by 2023)
  • Smart chatbots for personal healthcare
  • Assistants for detecting and responding to cyberattacks
  • Teaching assistants for self-paced online learning
  • Autonomous vehicles
  • Smart manufacturing
• Outreach to explain the huge opportunities for Cognitive AI
Cognitive AI

giving computing a human touch