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

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03 March 2020

*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

Chunks correspond to activation across bundles of nerve fibres, see Chris Eliasmith's work on <u>semantic pointers</u>

```
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

```
dog kindof  mammal
cat  kindof  mammal
```

is equivalent to

```
kindof {
    subject dog
    object mammal
}
kindof {
    subject cat
    object mammal
}
```

# 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 $\longrightarrow$ 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
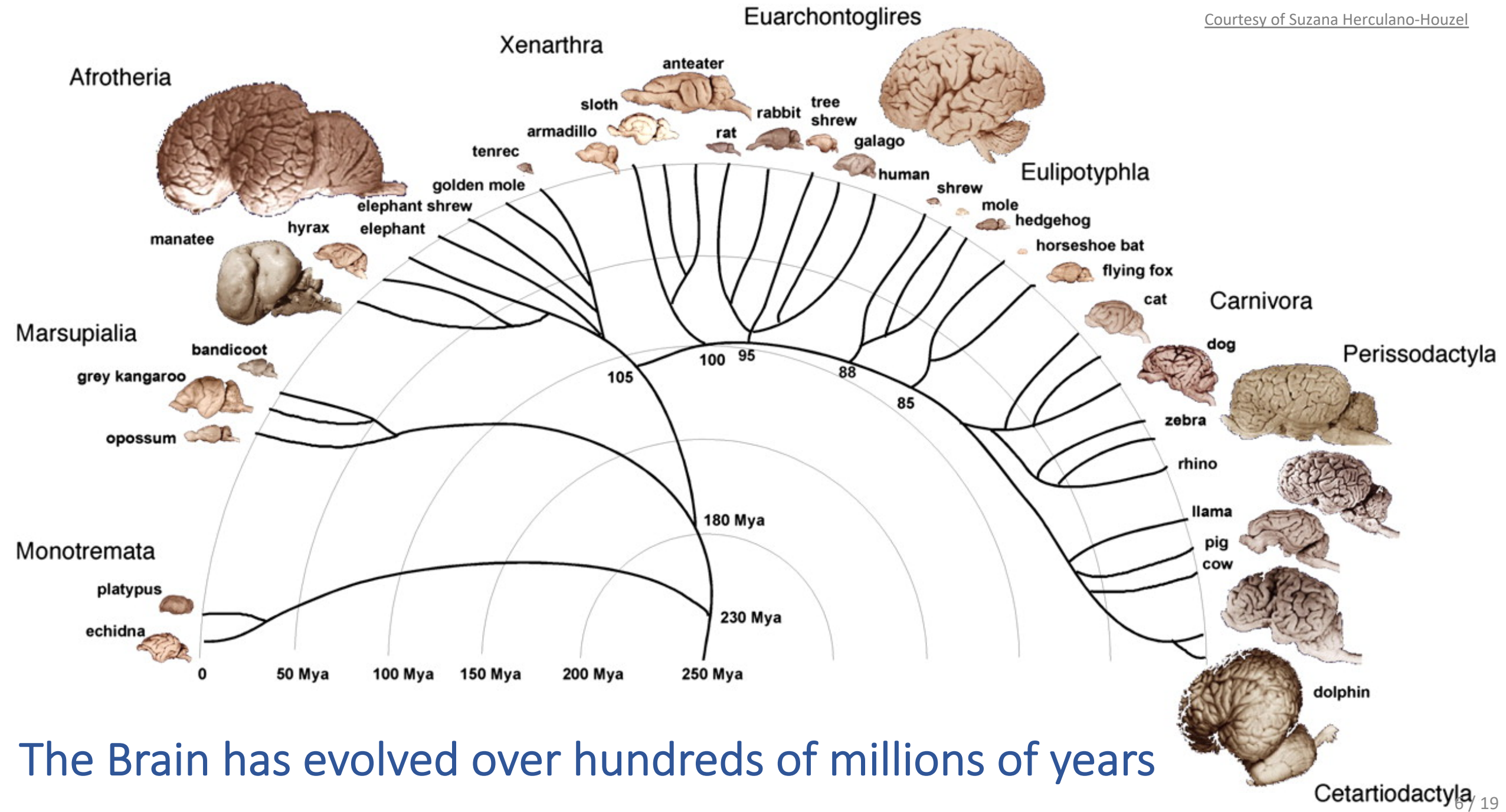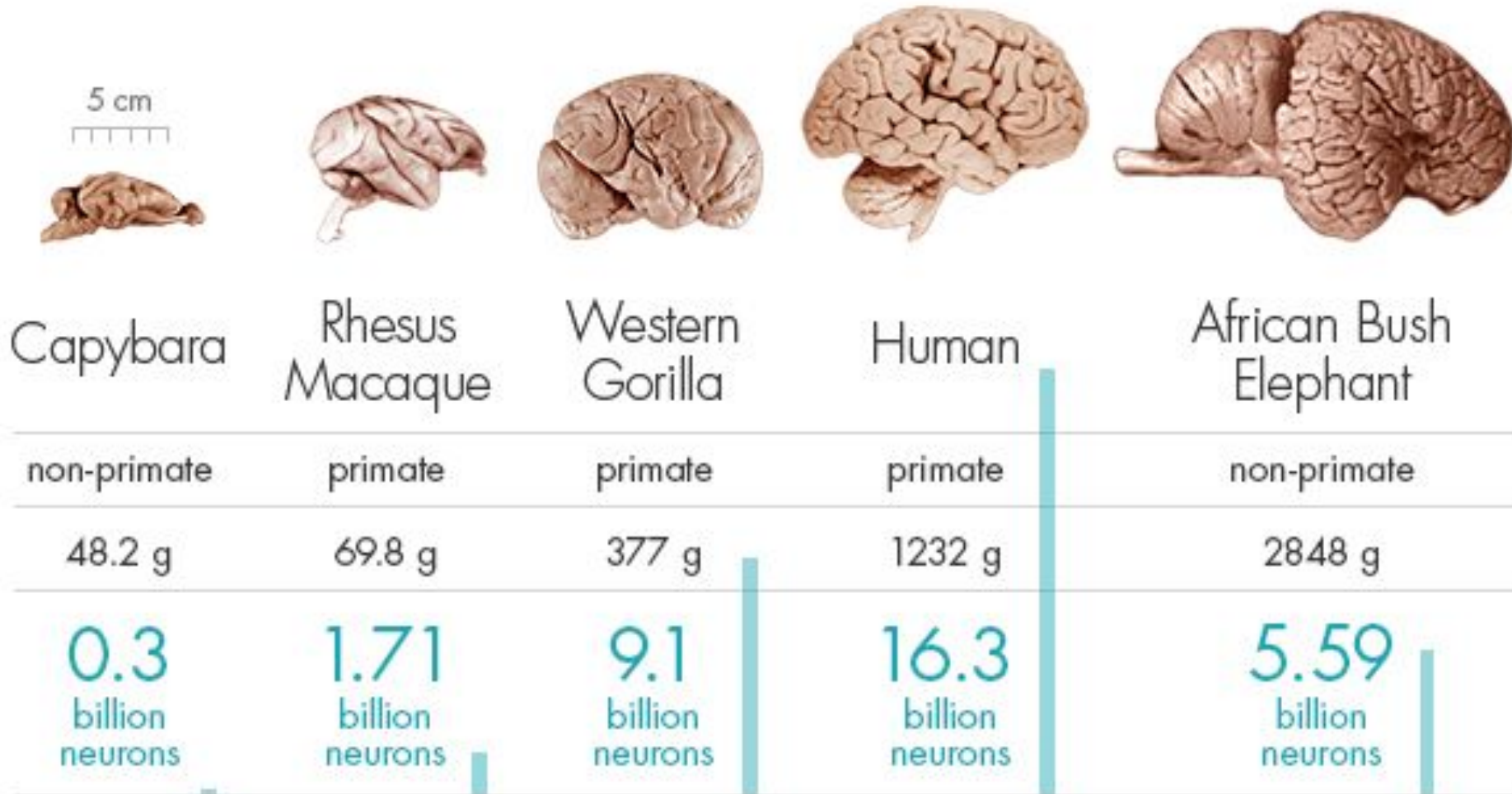
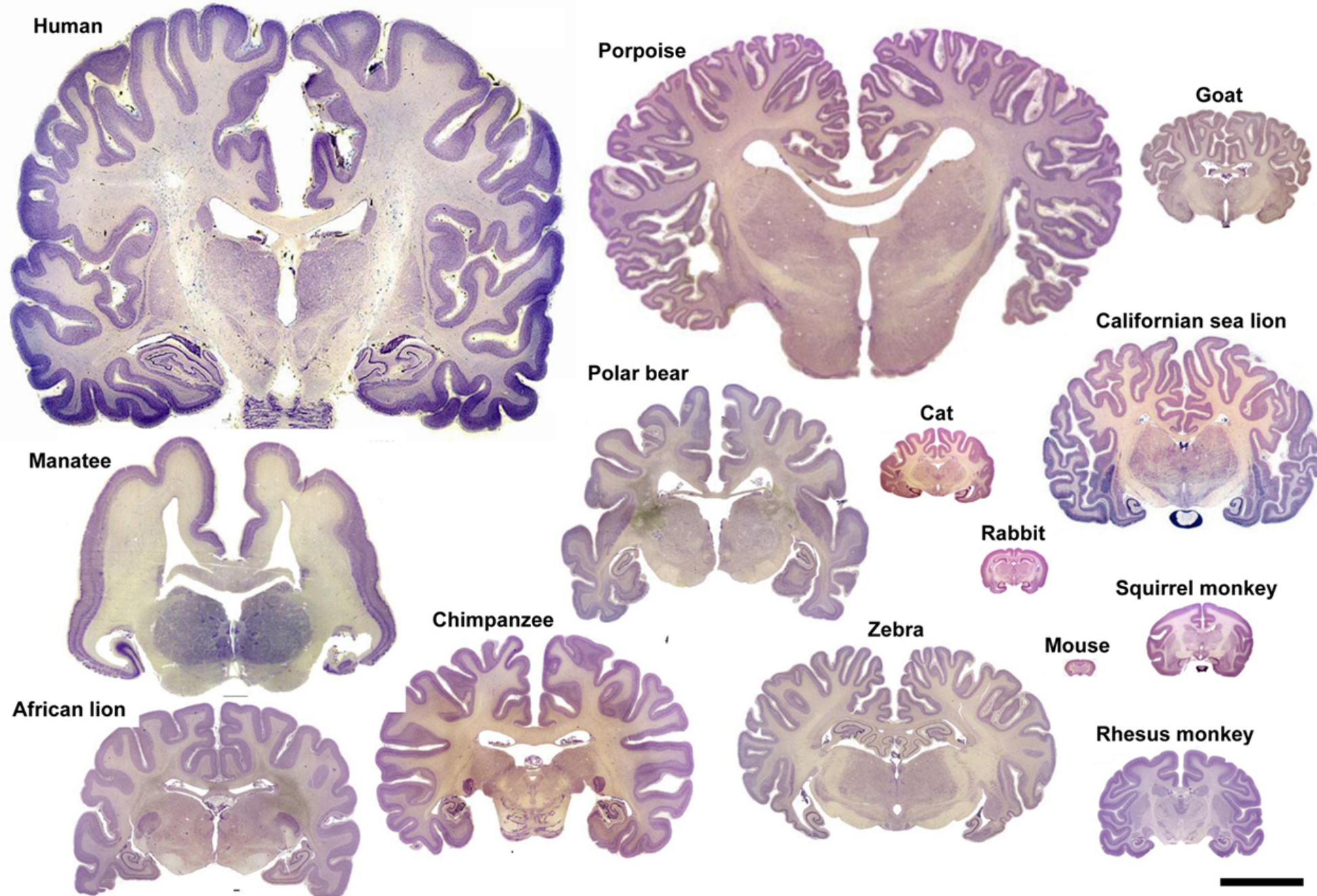The Brain has evolved over hundreds of millions of years

# BRAIN SIZE AND NEURON COUNT
Cerebral cortex mass and neuron count for various mammals.

Courtesy of Quanta magazine

5 cm

| | Capybara | Rhesus Macaque | Western Gorilla | Human | African Bush Elephant |
|---|---|---|---|---|---|
| | non-primate | primate | primate | primate | non-primate |
| | 48.2 g | 69.8 g | 377 g | 1232 g | 2848 g |
| | 0.3 billion neurons | 1.71 billion neurons | 9.1 billion neurons | 16.3 billion neurons | 5.59 billion neurons |

Note: across species, the cortex has under a third of the number of neurons in the cerebellum

Human

Porpoise

Goat

Californian sea lion

Manatee

Polar bear

Cat

Rabbit

Squirrel monkey

Mouse

Chimpanzee

Zebra

African lion

Rhesus monkey

# Brain function – many specialized areas



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

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

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

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

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

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

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
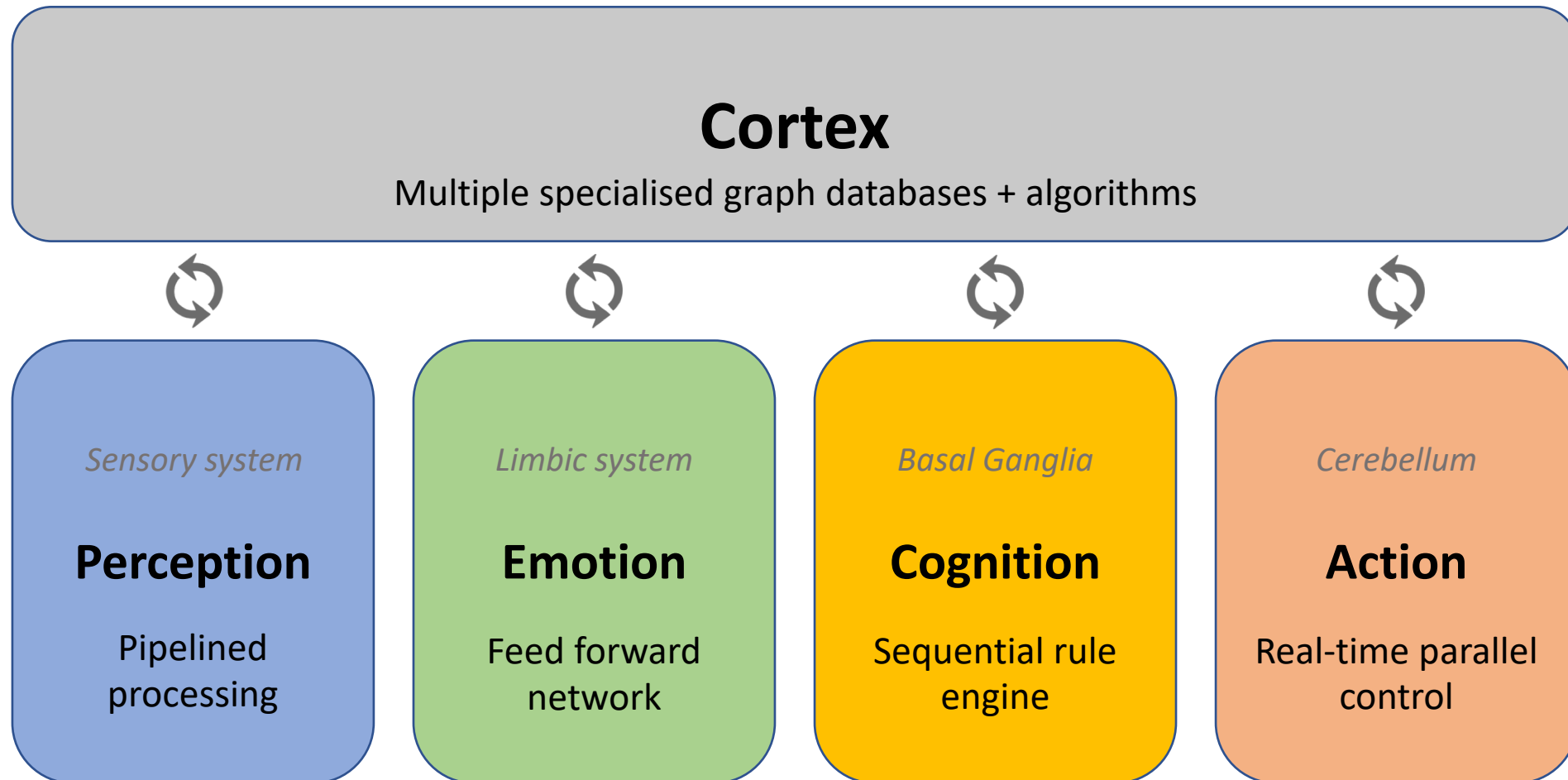
# Modelling the Cortex with Cognitive Databases

- 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

Visual system

Hearing
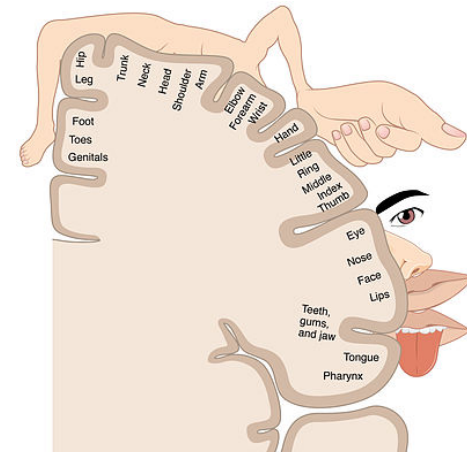
*Cortical homunculus*

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

**Chunks**: a collection of properties that include references to other chunks

**Modules**: specialised graph databases and algorithms, accessed via buffers that hold a single chunk

**Rules**: conditions ranging over module chunk buffers, and actions that either update the buffers or invoke graph algorithms

# 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

```
# 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



```
# 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}
```
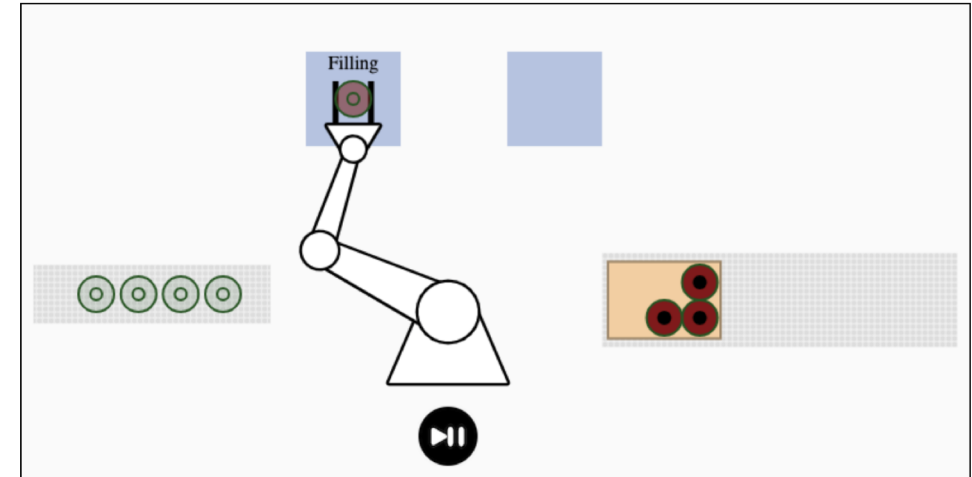
Log:

```
executed rule _:19 stop
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*