How Minds Work
Memories and Learning

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Human Learning

• More or less
  – Continual
  – Quick
  – Efficient
  – Accurate
  – Robust
  – Flexible
  – Effortless
Problems with Machine Learning

• Requires large, accurate training sets
• Little awareness of what’s known or not known
• Integrates new knowledge poorly into old
• Learns one task at a time
• Little transfer of learned knowledge to new tasks
• Poor at learning from human teachers
For more human-like learning in machines

Design autonomous software agents and mobile robots using principles from human learning
Some Principles of Human Learning

• There’s no learning from scratch
• We learn what we attend to
• Learning is a trial and error process
• Much memory is associative and content addressable
Lessons for Machine Learning

• Build in
  – Primitive feature detectors
  – Preferences for learnings
  – Attention mechanism
  – Base level activation
  – Inverse sigmoidal decay

• Make memory
  – Associative
  – Content addressable
Types of Human Learning Requiring Distinct Mechanisms

- Perceptual learning
  - Identify, classify, situate
- Episodic learning
  - What, where, when
- Procedural learning
  - New skills
  - Improve skills
  - Automatize
- Attentional learning
  - To what to attend
Examples of Learning Mechanisms

- Perceptual learning via a Slipnet
- Episodic learning via Sparse Distributed Memory
- Procedural learning via a Schema Net
A mechanism for perceptual learning

- Semantic net with activation passing
- Nodes represent features, individuals, categories, ideas
- Links represent relations, some excitatory, some inhibitory
- Total activation = current + base-level
- Percept composed of nodes over threshold
- Learning modifies base-level activation
A mechanism for episodic learning

- Sparse distributed memory
  - Few hard locations, HUGE address space
  - Each hard location contributes to the encoding of many different events
  - Each event is encoded to many different hard locations
- Associative and content addressable
- Psychological properties
  - Knows when it doesn’t know
  - Tip of the tongue phenomena
A Mechanism for Procedural Learning

- Procedural learning via a schema net
- Activation = current + base-level
- Procedural learning
  - Reinforces base-level activation
  - Forms new schemas
- Schemas instantiate, activate, bind
- Incremental learning produces new behavior streams
Cognitive Cycles

• Every autonomous agent operates in the world by frequent, probably cascading, sense-process-act cycles
• Learning takes place during each cycle
• Learning is a function of attention and of arousal level.
• Feelings and emotions modulate learning
Human Cognitive Cycle Processing

- **Hypothesis**— Human cognitive processing is via a continuing sequence of Cognitive Cycles

- **Duration**— Each cognitive cycle takes roughly 200 ms

- **Cascading**— Several cycles may have parts running simultaneously in parallel

- **Seriality**— Consciousness maintains serial order and the illusion of continuity

- **Start**— Cycle may start with action selection instead of perception
Perceptual Associate Memory

• Ability to interpret incoming stimuli by
  – recognizing individuals
  – categorizing them
  – noting situations
• Ubiquitous among animal species
• Animals of all sorts can identify food sources, potential mates, potential predators, etc.
Examples of PAM

• Pigeons – can categorize photos using such concepts as tree, fish, and human
• Honey bees – can identify letters independently of size, color, position or font
• African Grey Parrot (Alex) – can identify such features as size, number, color, and material of (sets of) objects never before seen
Perceptual Learning Premises

• (Almost?) ubiquitous among animals
• Evolutionarily older than semantic memory
• Distinct neural mechanisms
• Conscious awareness sufficient
• Facilitated by feelings and emotions
• Decays by an inverse sigmoid function
• First step in a sense-cognize-act cycle
Sensation

• Sensory receptors are directed by action
  – Saccades of the eyes
  – Sniff
  – Turing of an ear
  – Sending of an echolocation signal

• The environment impinges on receptors
Perception

- Filters sensory input based on expectation
- Simultaneously attaches meaning to it
- Identifies individuals, categories, situations and feelings
- Produces a percept including individuals, categories, relations, ideas, and some interpreted sensory data, i.e., qualia
Perception in IDA’s Cycle

• Input arrives through senses
• Perception codelets find features and activate appropriate nodes in the slipnet
• Activation passes from node to node until the slipnet stabilizes
• Streams from different senses converge & bits of meaning combine into larger chunks
• Nodes over threshold form the percept
• Sensory stimuli received & interpreted, producing initial meaning
Each Node a Feature Detector

- Primitive feature detector – direct connection to receptive field
- Higher level feature detectors combine lower level feature detectors
- Object nodes detect features of object
- Category nodes detect members as features, as well as other features
Perceptual Learning

• Using the broadcast contents of consciousness
• Strengthen (or weaken) existing objects, categories, ideas, relations, feelings, etc.
• Create new objects, categories, situations
Contents of Consciousness

- Slipnet nodes are perceptual symbols
- Uniform representation throughout the IDA model
- Slipnet nodes comprise conscious contents
Modifying Existing Nodes

• Current activation
  – from other nodes
  – starting with primitive feature detectors
  – rapid decay

• Base-level activation
  – Inverse sigmoidal decay

• Total node activation a function of current and base level activations

• Perceptual learning modifies base-level activation of each node in conscious contents
Inverse Sigmoidal Decay

- Low base-level activation = rapid decay
- Saturated base-level activation = almost no decay
Learning New Nodes

- Object nodes – from noting contiguity of motion of features
- Category nodes – from noting similarity of objects
- Requires specific attention codelets
- A generate & test procedure due to inverse sigmoidal decay
Transient Episodic Memory

- Records what, when, how, feelings, actions
- Content addressable from partial cues
- Consciously noted events are encoded
- Modulated by feelings and emotions
  - More affect, stronger encoding
  - More affect, more often in consciousness
- Decays in hours or a day
Writing to TEM

- Uses sparse distributed memory
- Perceptual symbols = universal representation
- Primitive feature detectors = subsets of dimensions
- Translate higher level feature detectors to primitive feature detectors for writing
Reading from TEM

- Contents of working memory form the cue
- Must be translated to primitive feature detectors
- Return from SDM routed through perception to produce perceptual symbols
Declarative Memory

- Autobiographical + semantic
- Read from just as TEM
- Write is consolidation from TEM
- Inverse sigmoidal decay
- Can decay very quickly
- Can last for decades
How Minds Work: Memory & Learning
Procedural Learning

- Learning new tasks - instructionist
- Reinforcing old tasks - selectionist
- Learning via consciousness
- Primitive effectors (motor neurons & muscles) not learned
- Very short term to very long term
Implementation

- Procedural learning via a schema net
- Schema (context, action, result)
  - = behavior codelet in priming mode
- Primitive effector = empty schema (only action)
- Links from schema to derived schema
Activation of a Schema

• Modify as a result of conscious content
• Base-level activation – reinforce if action succeeded
• Current activation – depends on
  – Relevance of context to current situation
  – Relevance of result to current goals or feelings
• Total activation = base-level + current
Decay of Schema Activation

- Base-level activation – inverse sigmoidal
  - Low level schemas decay very rapidly
  - Saturated schemas decay hardly at all
  - Learning can be short or long term
- Current activation decays rapidly
Selectionist Learning

• Selectionist = reinforcement
  – Conscious broadcast says expectation met
  – Affect valence positive
  – Increase base-level activation in proportion to affect level
  – Valence negative or expectation not met
  – Decrease base-level activation in proportion to affect level
Instructionist Learning

• Behavior = goal context = schema with parallel compound action
• Merge two schema into a third
• Behavior stream = goal context hierarchy = schema with sequential compound action
• Merge two schema into a third
Attentional Learning

• Built in attention codelets for
  – Temporal sequence (= causality)
  – Similarity (= categorization)
  – Contiguity of motion (= object formation)

• Expectation codelet spawned with each executed behavior (codelet)

• Intention codelet produced with each volitional decision

• Others learned?
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