# Web of Thought

The logical next step after the Web of Things

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# Web of Things

- Web technology for application / service layer
- **Things** include connected devices, people, places, abstract things e.g. concerts, organizations, and time periods (the 70's)
- Things have virtual representations – *Avatars*
- Avatars have identity, rich descriptions, services and access control
  - Avatars have URIs and are accessed via web technologies
- More details on the Web of Things
  - http://www.w3.org/2014/11/05-dsr-wot.pdf (Mindtrek 2014)
  - W3C Web of Things IG: http://www.w3.org/WoT/IG/

# What is the most important difference?

With thanks to the Westside story

vs


With thanks to PSDgraphics.com

# Common Sense!

# Web of Thought

involves

Avatars with common sense
that act as smart assistants

Accessible as part of the Web of Things

# Common Sense

- Knowledge and reasoning about everyday things
- People and personal relationships, space, time, causality and naïve physics, tools, the natural world, the urban world, story telling, humour, emotions, empathy, personality traits
  - and much much more ….
- How to accomplish everyday tasks
- When someone says something
  - What is implied based upon what I know?
  - Why did they say this?
  - What should I say in response?

# Emotions

- Understanding stories and actions at an emotional level
  - Modelling the emotions of others
    - What emotions are they experiencing
    - How is this expected to influence their behaviour
  - Taking this into account in conversational dialogues
    - What does it mean to exhibit empathy?
- Experiencing emotions
  - Enabling a cognitive system to experience emotions that guide its behaviour
- Appraisal Theory of emotion and cognition
  - What things determine your current emotional state?
    - Reactive (fast), deliberative (slow)
  - How does this state influence cognition?
  - Psi-theory drives and goals
    - Physiological, Social and Cognitive drives
    - Goals are situations in which urges are fulfilled
  - What is instinctive and what is learned from experience?

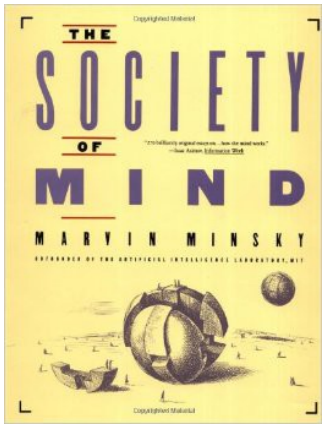
# Understanding Humour

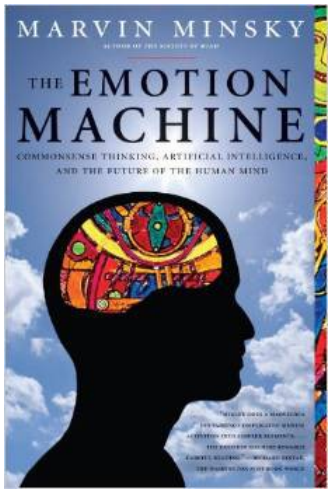
***For Sale: Parachute. Only used once, never opened.***

***I used to be a banker, but I lost interest.***

- Raskin's theory of incongruity resolution
  - Humour involves incongruous interpretations of a joke
  - The start of the joke invokes the “obvious” interpretation
  - The joke's punchline is inconsistent with the obvious interpretation and instead points to another incongruous interpretation
  - Understanding the punchline leads to relief expressed via laughter
  - People tend to just remember the punchline and the second interpretation
- Semantic jokes vs puns
  - Puns tend to rely on words that sound the same but have very different meanings
- Implications for cognitive architecture

# Structuring Skills




- Marvin Minsky's Society of Mind
  - Theory of natural intelligence published as a book in 1988
  - Intelligence treated as a collection of agents
  - Agents which activate other agents
    - Nemes invoke representations of things
    - Nomes control how representations are manipulated
  - Frames & slots as collections of properties for a given thing
    - Transframes for representing events
- Minsky's 2006 book “The Emotion Machine”
  - Knowing when a way of thinking isn't working
  - Activating a better way to think in this situation

# Multiple Levels of Reasoning

- Minsky proposes six levels of reasoning
  - Self-conscious reflection
    - Awareness of other people's feelings and matching up to your own ideals
  - Self-reflective thinking
    - Keeping track of your plans
  - Reflective thinking
    - Reflecting on recent experiences
  - Deliberative thinking
    - Review and selection from alternative courses of actions
  - Learned reactions
    - Behaviours and representations that are learned through experience
  - Instinctive reactions
    - Hardwired for rapid reactions, e.g. removing your hand from source of pain
- Implemented by Push Singh as EM-ONE
  - http://web.media.mit.edu/~push/push-thesis.pdf

# Narratives

- Narrative as a representation of an experience
  - An account of what you did in a particular situation
  - Together with annotations on what went well and what you could have done better
- Can be used as a basis for choosing a course of action
  - Search for relevant narratives
  - Adapt as needed to match current situation
- Stepping stone to learning how to react
  - Compiling rules based upon repeated experiences

# Why Logic alone isn't the answer

- Logic is attractive as a basis for reasoning
- Researchers have focused on formal proof procedures and completeness
- This is a distraction from the real world!
- Rule engines don't scale well, especially for 2nd and higher order logics
  - Common sense involves too many facts and rules
- Need to give up on completeness and proof
- Limit inference to what it useful based upon experience
  - How to focus on what's important to the current goals
  - Godel's incompleteness theorem
    - Not all things can be proved or disproved from first principles

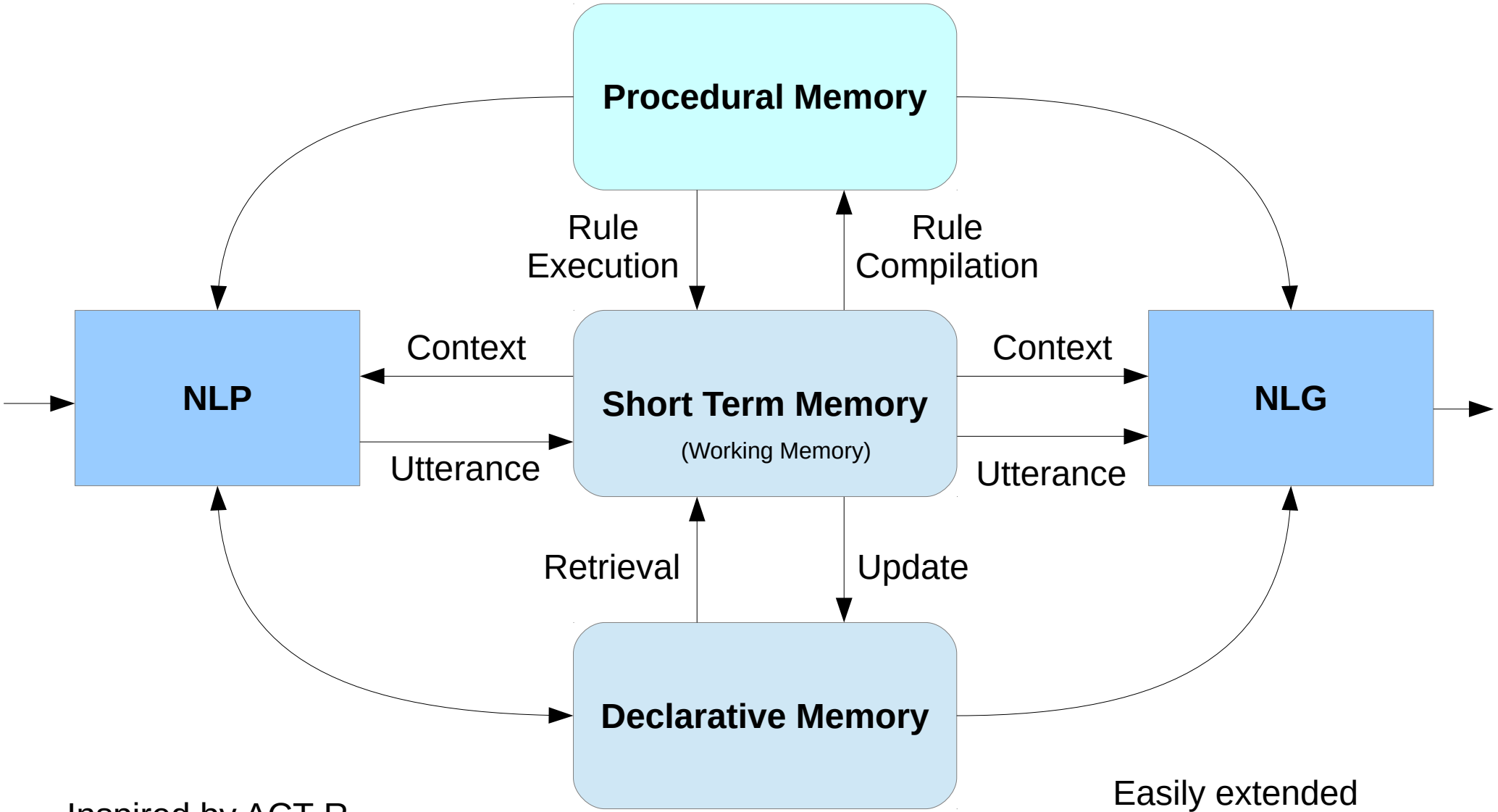
# Traditional Statistical Learning

- Need for very large corpus of examples
- Examples define input and output
  - e.g. text utterance and syntactic parse trees
- Split corpus into training and testing sets
  - Use training set to build statistical models
  - Use testing set to assess performance
- Not really practical for common sense
  - Difficulties in creating large corpus
- Why not do as humans do?
  - Use natural language interaction
  - Sequence of lessons with examples and tests
  - Incremental learning from small data sets

# Lesson plans for AIs

- Start with taxonomy of common sense
  - This will grow over time and doesn't need to be “complete” to start with
- Identify interdependencies to determine the order in which concepts need to be taught
- Construct lessons for each concept
- Lessons use simple natural language
  - Examples and counter examples
  - Assessment exercises
  - Revision for reinforcement

# Cognitive Architecture




Inspired by ACT-R

Easily extended to handle events

# Cognition

- Symbolic reasoning with chunks (n-tuples) and production rules
  - Chunks form semantic networks of arcs and nodes
- Short term memory as strictly limited resource
  - Strongly borne out by cognitive science experiments
- Spreading activation with excitory and inhibitory links
  - For word senses and declarative concepts
- Sub-symbolic reasoning with statistical models
  - Retrieval from declarative long term memory
  - Rule selection and conflict resolution
- Theory adopted from John R. Anderson's ACT-R*

* For more about ACT-R see http://act-r.psy.cmu.edu/about/

# Rational Thought

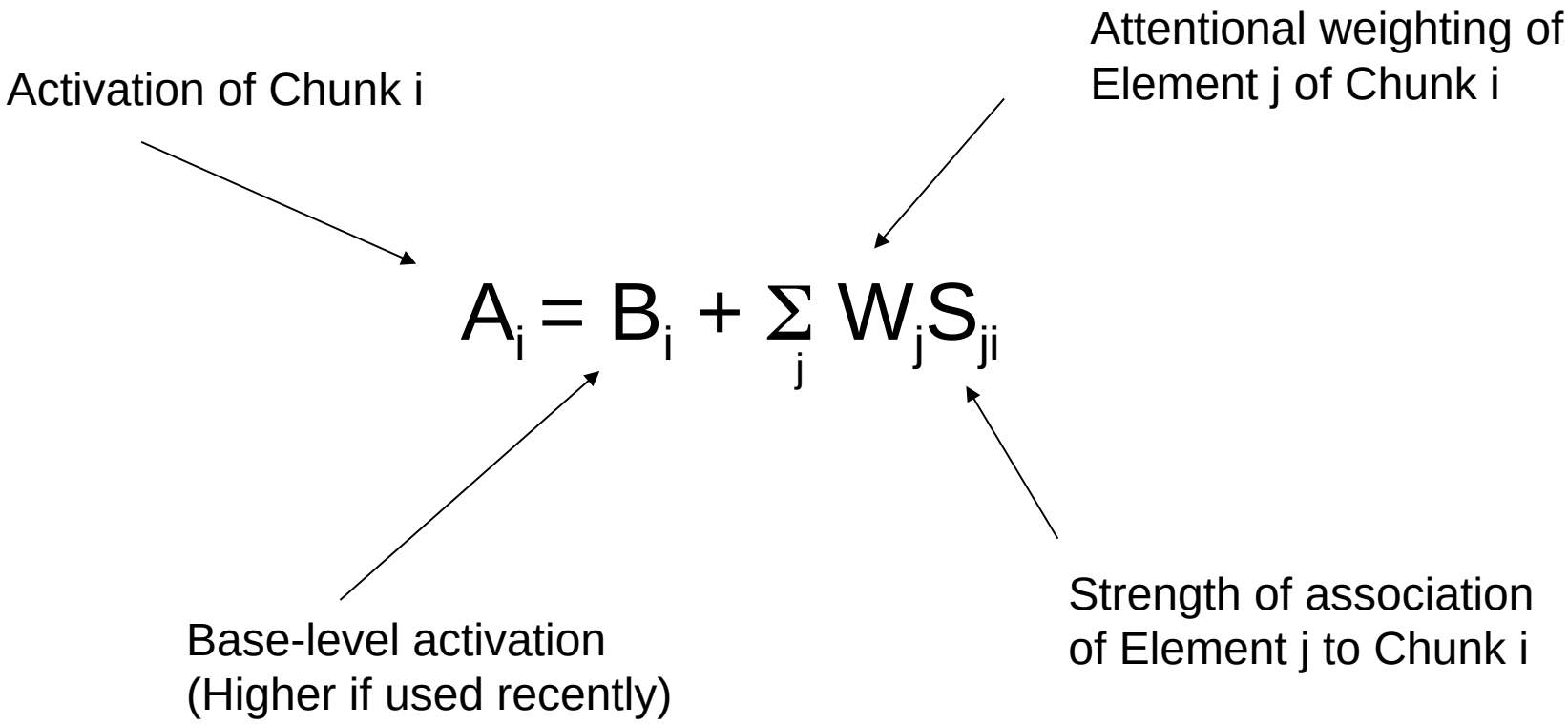
$$P(a|b) = \frac{P(a)P(b|a)}{P(b)}$$

- Making choices that reflect the statistics gained from experience
  - Bayesian statistics
    - Probability of **a** given observation **b**
    - Use past data to estimate P(a), P(b) and P(b|a)
  - Update probabilities as experience is gained

# Declarative Memory

- Facts vs episodic memories
  - Jupiter is a planet
    - Context independent facts
  - I had a pizza last night
    - Facts that hold in a given context
  - Yesterday, John told me that he loves Mary
    - Reported facts
- Stories, imaginary and counter-factual knowledge
- Memories fade with time
  - The more you use a memory, the more likely it is to be relevant
- Memories can be strengthened by the context in which they occur
  - Retrieval of one memory can make another easier to recall
- Memories can be decontextulalized if they occur frequently in many different contexts

# Chunk Activation




Probability of chunk retrieval is $P_i = 1 / (1 + \exp(-(A_i - \tau)/s))$

# Production Rules

- Conditions on short term memory and current input utterance
  - Small set of logical and string operators
- Actions include
  - Asynchronous retrieval from long term declarative memory
  - Updates to short term memory and generation of output utterance
- Rule variables with unification across variable instances
- Rules mapped to discrimination lattice for efficient evaluation of conditions
- Conflict resolution (see ACT-R)
  - Estimate of rule utility based upon its relative benefit & cost
- Reinforcement of successful rules (see ACT-R)
- Compilation of rules from repeated experiences

# Short Term Memory

- Constrained resource
  - Humans have very limited short term memory
    - Necessary for focussing conscious attention
    - Chunking as a limited work around
  - Older memories displaced by newer ones
- Combination of data and goals
  - Allows for reflection on goals
- Multiple levels of abstraction
  - Minsky describes
    - Instinctive, learned, deliberative, reflective, self-reflective, self conscious levels of thinking
  - Social and emotional models
    - How we see ourselves in relation to others

# Natural Language Input

- Lexical processing for part of speech
  - Ignore punctuation (for the most part)
- Syntactic processing for grammar rules
  - Chart parser with competing incremental results
  - Loose grammar rules to avoid premature bindings
- Word sense selection through spreading activation
- Prepositional attachment through rules and STM*
- Resolution of Pronouns through rules and STM*
- Reinforcement from successful parses
- Dealing with unknown words
  - Most commonly proper names

* STM – short term memory

# Natural Language

- Statistics for
  - Parts of speech
    - Based upon individual words, and preceding or following parts of speech
      - Recognition of compound words
  - Grammar rules
    - Based upon sequence of parts of speech
  - Word senses
    - Based upon semantic consistency
      - Spreading activation through memory
        - Is this adjective applicable to this noun?
  - Prepositional attachments
    - Verb cases with semantic and syntactic consistency
  - Bindings for indefinite pronouns
    - Role in dialogue

# Natural Language Output

- Maps utterance chunk into natural language
  - In most cases a single sentence
- Find verb then deal with subject, object and prepositional phrases
- Use context to replace nouns with pronouns
- Choose between alternatives based upon frequency data from natural language input

# Non-Verbal Communication

- Textual communication simplifies study of common sense reasoning skills
- Realistic avatars will require spoken dialogues and non-verbal communication
- Vocal stress and emotional speech
- Head and facial gestures
  - Speaker – for emphasis and to check if listener agrees
  - Listener to indicate agreement or disagreement
  - Rich facial gestures to convey emotional responses
    - e.g. smiling when someone does what you want
  - Social cues, e.g. when to engage in eye contact

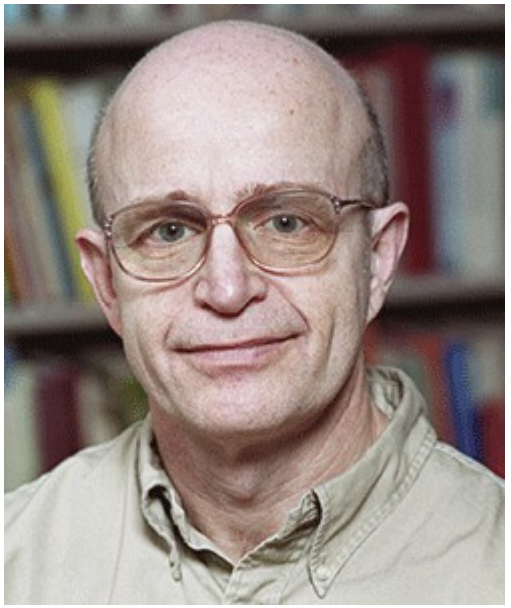
# Next Steps

- Study ACT-R for
  - Semantics of rule conditions and actions
    - Details for how utility is computed
  - Full details for memory retrieval/update
    - Functional interface definition
    - Mathematical model for subsymbolic processing
    - Algorithms for efficient subsymbolic processing
      - Use of hardware acceleration, e.g. graphics chips
  - How to constrain working memory
- Separate rule engines for each level of reasoning?
  - Does reasoning proceed asynchronously at different levels?
- Define human friendly syntax for facts/rules
  - As basis for serialization and debugging
- Define test framework for modules
- Develop tests and modules
- Integrate modules into complete system

# Long Term

- Define evolving taxonomy of common sense
  - Study interdependencies of concepts
- Define lesson plans
  - Learning by rote
  - Understanding examples
  - Learning by problem solving
  - Assessments
    - Ability to understand and solve tests
    - Ability to respond to questions about understanding
- Implement and evolve along with lesson plans
  - Lessons correspond to test suite
  - Blend of hard coded facts & rules
    and those learned during the lessons
    - With inspiration from Minsky's books
  - Re-run lessons after changes to check results
- Likely to take many years of work …

# With special thanks to



John R. Anderson

Marvin Minksky

As well as all the other pioneers in Cognitive Science and Artificial Intelligence