25 years of ILP

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June, 2010
ILP biography

**Infancy (1991-1994) - prodigious beginnings**
- Formal basis - eg inverse resolution, saturation
- Initial implementations - eg FOIL, Golem, Clint, Linus
- Early applications - eg finite element mesh, proteins

**Childhood (1995-2001) - logical development**
- Rigorous theoretical foundations
- Advanced implementations, eg Progol, Aleph, Tilde
- Significant applications - eg mutagenesis

**Teenage years (2002-2010) - indecision**
- Probabilistic logic representations, eg SLPs, DTLPs
- PLL implementations - eg Prism, ProbLog
- Larger significant applications - eg robot scientist
Now and Next

Young adulthood (2011-2015) - action and dynamism
- Metalogical and functional extensions
- Learning actions and strategies
- Hard applications - eg systems biology

Middle adulthood (2015-2020) - socialisation
- Integration of learning, perception and action
- Learning social skills
- Hard applications - eg synthetic ecology
# Human vs Statistical Learning

**UK EPSRC Priority 2016-2021 - Human-like Computing**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Human</th>
<th>Statistical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples per concept</td>
<td>Few ($\approx 1$) [Tenenbaum, 2011]</td>
<td>Many ($\geq 10K$)</td>
</tr>
<tr>
<td>Concepts</td>
<td>Many ($\geq 10K$) [Brown et al, 2008]</td>
<td>Few ($\approx 1$)</td>
</tr>
<tr>
<td>Background knowledge</td>
<td>Large [Brown, 2000]</td>
<td>Small</td>
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</tbody>
</table>
Trends

Endogenous
- Probabilistic ILP (aging)
- Declarative learning/mining
- Higher-order, meta-interpretable, predicate invention

Exogenous
- Lifted modeling (graphical models and beyond)
- Semantic web, description logics & co (decline?)
- Deep learning
Deep Learning Inspirations

Tricks for predicate invention

- unlabeled data, autoencoders, denoisers, ...
- mainly in the presence of big data

Revival of NN/Logic techniques in the deep context

- KBANN, C-ILP, ...

Lifted neural networks

- Logical prescriptions for unfolding ground networks
- Co-evolution of weights
Trends

Trends at ILP 2011-2015

- Strong subfields
  1. Propositionalization
  2. Graph Mining
  3. Feature construction
  4. Hybrid architectures: SVM, Neural Nets

- Growing number of applications
  1. Robotics
  2. Actions
  3. Reinforcement learning
  4. Bioinformatics
  5. Cognition

- Ongoing work on logical foundations
- Growing work on description logics
- Probabilistic Logic Learning/Statistical Relational Learning

Riguzzi (UNIFE)
The future of ILP

- Stronger connection to the Semantic Web
- Exploiting Linked Open Data
- Probabilistic Logic Learning/Statistical Relational Learning
  - tractable languages
  - tractable inference (lifted)
  - scaling
- Declarative learning: Constraints, ASP
- Applications to Big Data/Scaling: clusters, GPUs
Digits and Letters

Gerson Zaverucha
Vítor Santos Costa
ILP’13
Real **hard** progress in bridging numeric and symbolic approaches:

– ProbLog is now used in real applications
– NELL has 50 million beliefs
– CP-Lint applies sophisticated search works
– Relational Dependency Networks + Boosting is the relational algorithm to beat
Progress in Logic:

- Abduction of Rules (Meta-Rules)
  - Probabilities
  - Predicate Invention
  - Recursion

- Learning with Negation
Looking Ahead

• Big Data?

• Propositionalization

• Parallelism

• Applications
Trends and Outlook

- **Looking back**
  - Applications play a central role: Biology, medicine, robotics, natural language, vision, etc.
  - Different learning settings: Combinations of logic and probability, graphs, time and dynamics, etc.

- **Going forward**
  - Learn from very few examples and lots of knowledge
  - Automate ILP setup: Discover background knowledge in one domain and reuse it to solve other problems
  - Learn from both discrete and continuous data
  - Continue to focus on theory and applications
  - Make systems and data publicly available
ILP 2015

PANEL FROM VIEWPOINT OF ILP 2015

Katsumi Inoue, NII
Hayato Ohwada, Tokyo University of Science
Akihiro Yamamoto, Kyoto University
Trends

• **Declarative learning:** Some declarativeness everywhere in the forms of constraints, graphs, actions, kernels, ontologies, etc.

• **Modeling rather than simple learning:** Biology, robotics, data, natural language, cognition, vision

• **New applications:** logic, proof, strategy, etc.

• **Diversity of approaches and topics:** Continue to focus on theory and applications

• **Learning with meta-theories:** Meta-interpretive learning, meta-level abduction, etc.

• **Learning from time-series data**

• **Learning from both discrete and continuous data**
Outlooks

• Learning from few examples and commonsense
• Learning from state transitions with lots of fluents
• Integration of inference with high-level logical representation and recognition with low-level numerical data
• Deep relational learning—How they look like?
• General intelligence and learning
Recent technologies (word2vector, relation extraction, FreeBase, ...) provide millions of propositions learned from big data that ILP can exploit:

big data \rightarrow propositions \rightarrow ILP \rightarrow knowledge

- Propositions such as friend(X,Y), buys(X,Y,Z) can be non-traditional:
  - X,Y,Z are random vectors of (latent) features representing entities
  - Relations are matrixes and their truth value is computed like:
    \text{friend}(e1,e2) = \sigma((\text{friendM}(e1) \cdot e2)) \in [0,1]
  - Inferences are made logically or possibly by matrix (tensor) operations