The 30 Years War (1618–1648)

- reduction in German population 15–30%
- in some territories 3/4 of the population died
- male population reduced by almost half
- population of Czech lands reduced by 1/3
Leibniz's dream:

"a general method in which all truths of the reason would be reduced to a kind of calculation. At the same time this would be a sort of universal language or script, but infinitely different from all those projected hitherto; for the symbols and even the words in it would direct reason; and errors, except those of fact, would be mere mistakes in calculation."

If controversies were to arise, "there would be no more need of disputation between two philosophers than between two accountants. For it would suffice to take their pencils in their hands, and say to each other: Let us calculate."

_Dissertio de Arte Combinatoria_, 1666
Logic in Practice

- Natural Deduction
- Inference Rules
- Horn Clauses
- Semantic Nets
- Description Logic
- Example DL
- Break

ILP

Logics of Action
Natural Deduction

1. given \( \exists \), can introduce new constant
2. given sentence with ground expression, can introduce \( \exists \)
3. given \( \forall \), can introduce new constant
4. given sentence, can introduce \( \forall \) over new free variable

\( \land \) elimination/introduction:
\( \lor \) introduction:
\( \neg \neg \) elimination:
Inference Rules

Modus Ponens:

Resolution:

Abduction:

Induction:

mathematical induction ≠ inductive reasoning
Leibniz

Logic in Practice
- Natural Deduction
- Inference Rules
- **Horn Clauses**
- Semantic Nets
- Description Logic
- Example DL
- Break

ILP

Logics of Action

\[ x \land y \rightarrow z \]
Alfred Horn (1951)

\[ x \land y \rightarrow z \equiv \neg x \lor \neg y \lor z \]

at most one positive literal (exactly one = ‘definite clause’)

Cat(x) :- Furry(x), Meows(x).
Cat(y) :- Feline(y).
Furry(A).
Meows(A).
? Cat(z).

Still semi-decidable in first-order case.

Propositional: Unit resolution (Modus Ponens) is sound and complete in linear time for Horn theories: ‘forward chaining’.
Each rule ‘fires’ at most once, each variable ‘processed’ at most once

‘expert systems’
Semantic Networks

Leibniz

Logic in Practice
- Natural Deduction
- Inference Rules
- Horn Clauses
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- Example DL
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ILP

Logics of Action

Wheeler Rumel (UNH)
Multiple aspects:

- A visual notation
- A restricted logic
- A set of implementation tricks

Typically:

- Efficient indexing
- Precomputation
- Methods for defaults or typicality

Aka: frames, inheritance networks, semantic graphs, description logics, terminological logics, ontologies
computing categories and membership including:

1. subsumption
2. classification
3. inheritance

missing:

1. negation
2. disjunction
3. nested functions
4. existentials
5. intractability
1. concepts (primitive and derived), instances
2. roles (definitional) and properties (assertional)
3. subsumption: \( \text{subsumes} (x, y) \) iff
   
   \((a)\) \( x \) is a concept, and
   
   \((b)\) same primitive concept ancestor, and
   
   \((c)\) for each role of \( x \) with restriction \( r_x \)

   \quad \text{i.} \ y \text{ has same role with restriction } r_y \text{, and}
   
   \quad \text{ii.} \ r_x \text{ subsumes } r_y
assts 6, 7
asst 8
preliminary proposals due next class
Inductive Logic Programming
Three types:

**Supervised:** classification (≡ prediction of class)
**Unsupervised:** compression (≡ prediction of actual value)
**Reinforcement:** sequence of decisions with occasional reward

Each can be on-line (incremental) or off-line (batch).

**Terminology:**
1. Hypothesis space
2. Training data (vs test data, for off-line case)
3. Performance metric (often on validation data)
Given: ground facts and background definitions
Find: short (almost Horn) clauses that cover positive examples and not negative ones

\[ \text{Background} \land \text{Hypothesis} \land \text{Descriptions} \models \text{Classifications} \]
Descriptions:
- Father(Philip, Charles)
- Father(Philip, Anne)
- Mother(Mum, Margaret)
- Mother(Mum, Elizabeth)
- Married(Diana, Charles)
- Married(Elizabeth, Philip)
- Male(Philip)
- Male(Charles)
- Female(Beatrice)
- Female(Margaret)

Classifications:
- Grandparent(Mum, Charles)
- Grandparent(Elizabeth, Beatrice)
- ¬Grandparent(Mum, Harry)
- ¬Grandparent(Spencer, Peter)

Background: \( \text{Parent}(x,y) \leftrightarrow \text{Mother}(x,y) \lor \text{Father}(x,y) \)
Given: ground facts and background definitions
Find: short (almost Horn) clauses that cover positive examples and not negative ones

**Sequential covering** (‘FOIL’)

\[
\text{rules} \leftarrow \{ \}
\]

Until no remaining positives (or good enough):

1. \( \text{new} \leftarrow \text{empty rule} \)
2. While false positives (eg, covers any negatives):
   1. Add best single literal precondition
   2. Add \text{new} to \text{rules}
3. Remove positive examples covered by \text{new}
Example

$\rightarrow Grandfather(x,y)$
\[ \rightarrow \text{Grandfather}(x,y) \]

\[ \text{Father}(x,y) \rightarrow \text{Grandfather}(x,y) \]  
(always wrong)

\[ \text{Parent}(x,y) \rightarrow \text{Grandfather}(x,y) \]  
(many false +)

\[ \text{Father}(x,z) \rightarrow \text{Grandfather}(x,y) \]  
(selected)
Example

\[ \rightarrow \text{Grandfather}(x,y) \]

\[
\begin{align*}
\text{Father}(x,y) & \rightarrow \text{Grandfather}(x,y) & \text{(always wrong)} \\
\text{Parent}(x,y) & \rightarrow \text{Grandfather}(x,y) & \text{(many false +)} \\
\text{Father}(x,z) & \rightarrow \text{Grandfather}(x,y) & \text{(selected)} \\
\text{Father}(x,z) \land \text{Parent}(z,y) & \rightarrow \text{Grandfather}(x,y) & \text{(target)}
\end{align*}
\]
New literals:

1. Any predicate over any variables, where at least one of the variables is in previous literal or head
2. Equal(x, y), where x and y are already in rule
3. Negation of any of the above

Best: maximizes ‘information gain’

Clause must be shorter than positives it explains (cf Ockham’s razor).
1. Mutagenesis
2. Toxicity
3. Rules of chess
4. Protein structure
5. Parsers
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Logics of Action
Events and fluents are reified:

\[ \text{Member}(E23, \text{Flyings}) \land \text{Agent}(E23, \text{John}) \land \text{Happens}(E23, I7) \ldots \]

\[ T(\text{At}(\text{John}, \text{KN133}), t_1) \land \text{Terminates}(E23, \text{At}(\text{John}, \text{KN133}), t_2). \]
World state (= situation) is reified:

\[ \text{Result}(\text{GoForward}, s_0) = s_1 \]

\[ \text{Result}(\text{Turn(right)}, s_1) = s_2 \]

\[ \forall s, a, b \, \text{Clear}(a, s) \land \text{Clear}(b, s) \rightarrow \text{On}(a, b, \text{Result}(\text{PutOn}(a, b), s)) \]
Defaults: hard to have coherent semantics and efficient inference (default logics, answer set programming, probabilistic logic)

Ramification problem: choosing what to infer (specialized systems)

Retraction: when previous truth becomes false (truth maintenance systems)

Qualification problem: making rules correct (probabilistic logic)
What question didn’t you get to ask today?
What’s still confusing?
What would you like to hear more about?

Please write down your most pressing question about AI and put it in the box on your way out.

Thanks!