Expert Systems
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CS 640
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The Zoo Keeper Example is by P. Winston.

What is an Expert System?

Expert system =

Knowledge-based system =

Knowledge navigator =

Rule-based system =

Deduction/reaction system =

Recommendation system =

Software agent

Early Successful Expert Systems

Most Famous Industry Products:

- Mavent: Mortgage Loan Advisor checks compliance with Truth-in-lending Act (28 million loan reviews as of 1/2017)
- Mycin: recommended antibiotics
- XCON: eXpert CONfigurer for computer components for DEC VAX

Early Successful Expert Systems

LIMEX: Assessment, irrigation, fertilization, and pest control recommendations to assist lime growers

Many more agricultural expert systems:

- Tomatex (tomatoes)
- Neper Wheat
- Citex (oranges)
- Cupex (cucumbers)

Not so successful Office Assistants

Microsoft’s "Clippit" or "Clippy"

Apple’s bow-tied software assistant: handle calendar, phone calls, discuss rainforest deforestation, etc.

Expectation up to recently

Expert Systems based on

- hand-crafted rules and
- search algorithms like
  - Depth-First-Search (DFS) or
  - Bread-First-Search (BFS)

would be replaced by systems based on Machine Learning.

This has only happened for some tasks.

State of the Art in 2018

Industrial Research on Knowledge-based Systems has focused on Predictive Medicine with Machine Learning:

- DeepMind Technologies: Analysis of eye scans, searching for early signs of diseases leading to blindness (2016)
- Soma Logic Inc.: Heart attack prediction via analysis of blood proteins (2016)
- Myriad Genetics Inc.: Molecular diagnostics to predict hereditary cancer risk (2015)

Break-through product

Medial EarlySign

- Medi=medical, al=algorithm
- Company founded by Kalkstein 2009

ML software trained on 2 million records, identifies 10x normal risk of colon cancer from blood test

Used by U.S. Kaiser Permanente HMO & second largest Israeli health care provider

References

- Various wiki pages (see links on course page)
- Bloomberg Business Week, January 15, 2018

Research Trend since 2020

- Early, rule-based approaches to expert systems need to be understood to develop a new-generation expert system
- Pure data-based (statistical) machine learning may not be the answer
- Recent research trend: Combination of rule-based systems and knowledge bases (domain knowledge) with statistical machine learning systems

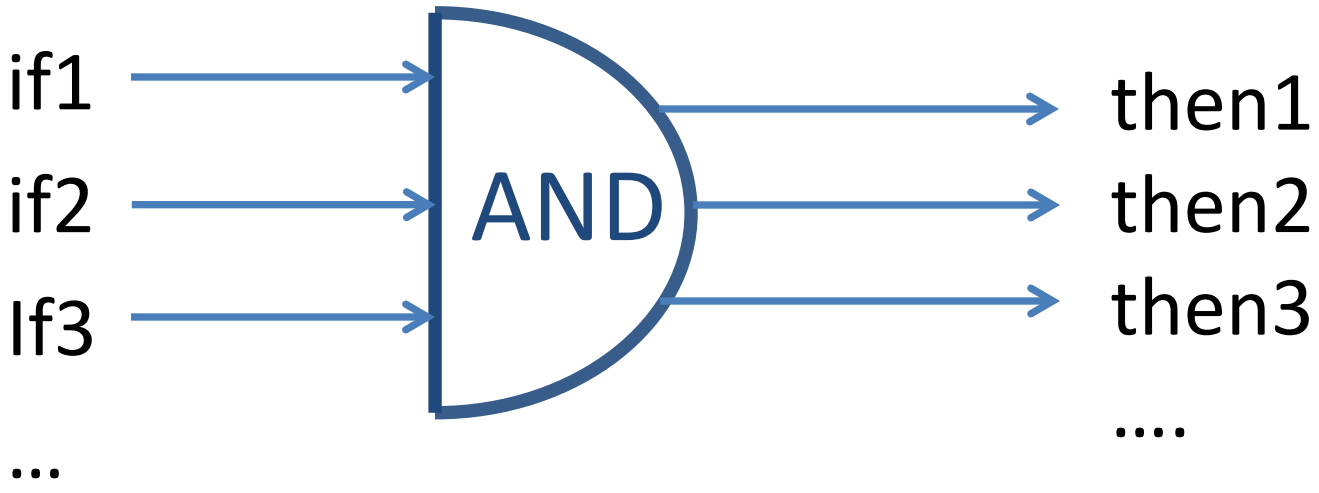
Types of Expert Systems, Rule Syntax

Rule-based Deduction Systems
Reaction Systems

Rule Syntax:

R_n : IF if1 — antecedents
if2
…
THEN then1 — consequents
then2
then3
…

Circuit Visualization



Terminology

- Antecedent = assertion
- Consequent = assertion in deduction system
  = reaction in reaction systems

Fact = something true (never false)

Assertion = statement that something is true
(can be false)

e.g. “It is raining today”

“It is sunny today, 9/10/2020” T or F?

Terminology

"Working Memory" = collection of assertions

"Forward Chaining" = moving from IF to THEN:

IF *all antecedents of R satisfied*

THEN *rule is "triggered"* or

action is "fired"

Example: Zookeeper

- Deduction system to identify animals in a zoo
- Reference: Patrick Winston's AI book
- 7 animals:

  Cheetah, tiger, giraffe, zebra, ostrich, penguin, albatross

<u>1st idea: Build a rule for each type of animal:</u>

R_n : IF *all characteristics of an animal*
THEN *This is animal of type n*

=> 7 rules with long list of antecedents

Zookeeper Expert System

2nd idea:

- Reduce number of antecedents by checking common characteristics
- Produce intermediate assertions
- Compute chains of conclusions

Z1: IF *?x has hair*

THEN *?x is a mammal*

?x is a variable

More Terminology

- If the assertion “Stretch has hair” is in the working memory, variable x can be bound to Stretch
- We also say “Stretch is the binding of x”
- If all variable in the antecedent are bound, the rule is instantiated

Zookeeper Rules

Z1: IF ?x has hair
THEN ?x is a mammal

Z2: IF ?x gives milk
THEN ?x is a mammal

Z3: IF ?x has feathers
THEN ?x is a bird

Z4: IF ?x flies
?x lays eggs
THEN ?x is a bird

Z5: IF ?x is a mammal
?x eats meat
THEN ?x is a carnivore

Z6: IF ?x is a mammal
?x has pointed teeth
?x has claws
?x has forward-pointing eyes
THEN ?x is a carnivore

Z7: IF ?x is a mammal
?x has hoofs
THEN ?x is an ungulate

Z8: IF ?x is a mammal
?x chews cud
THEN ?x is an ungulate

Zookeeper Rules

Z9: IF ?x is a carnivore
?x has tawny color
?x has dark spots
THEN ?x is a cheetah

Z10: IF ?x is a carnivore
?x has tawny color
?x has black strips
THEN ?x is a tiger

Z11: IF ?x is an ungulate
?x has long legs
?x has long neck
?x has tawny color
?x has dark spots
THEN ?x is a giraffe

Z12: IF ?x is an ungulate
?x has white color
?x has black stripes
THEN ?x is a zebra

Z13: IF ?x is a bird
?x does not fly
?x has long legs
?x has long neck
?x is black and white
THEN ?x is an ostrich

Z14: IF ?x is a bird
?x does not fly
?x swims
?x is black and white
THEN ?x is a penguin

Z15: IF ?x is a bird
?x is a good flyer
THEN ?x is an albatross

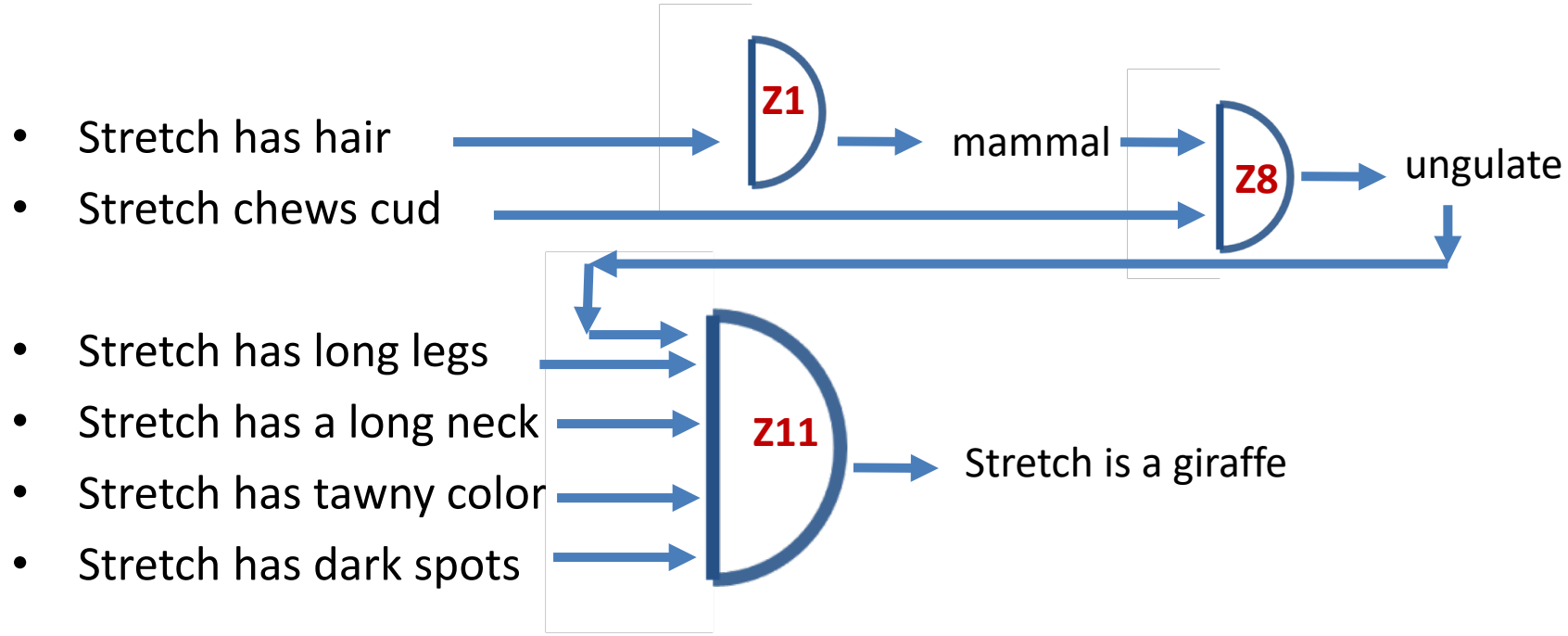
Working Memory

- Stretch has hair
- Stretch chews cud
- Stretch has long legs
- Stretch has a long neck
- Stretch has tawny color
- Stretch has dark spots

Forward Chaining Procedure

- Until no rule produces a new assertion,
  - For each rule,
    - For each set of possible variable bindings determined by matching the antecedents to working memory,
      - Instantiate the consequent.
      - Determine whether the instantiated consequent is already asserted. If it is not, assert it.

Example of Forward Chaining



Backward Chaining Procedure

- Find a rule whose consequent matches the hypothesis and create a binding set
- Try to support each of the rule's antecedents by matching it to assertions in the working memory or by backward chaining through another rule, creating new hypotheses. Be sure to check all matching and instantiation alternatives.
- If all the rule's antecedents are supported, announce success and conclude that the hypothesis is true.

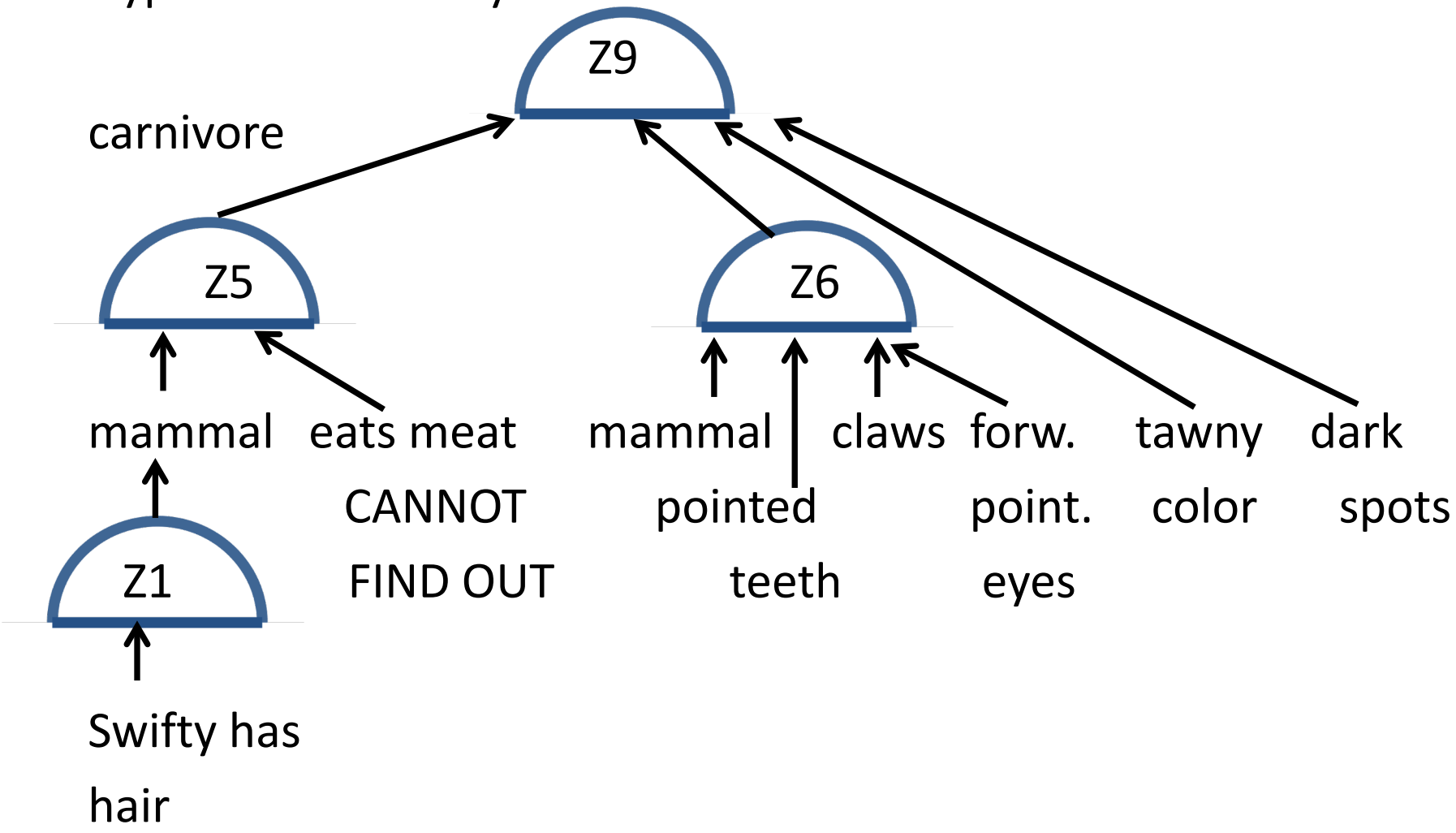
Circuit Visualization for Backward Chaining

Working Memory:

Swifty has hair
Swifty has pointed teeth
Swifty has claws
Swifty has forward pointing eyes
Swifty has tawny color
Swifty has dark spots

Hypothesis: “Swifty is a cheetah”

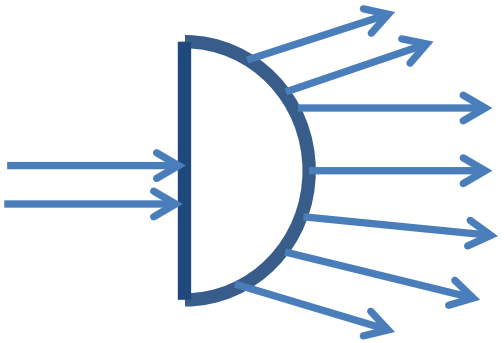
Circuit Visualization for Backward Chaining



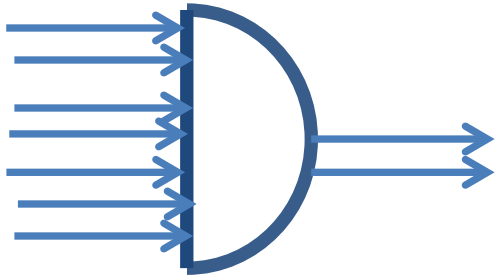
Forward vs. Backward Chaining

- More detailed pseudocode on course webpage
- Which direction is better?

Fan-in << Fan-out



Fan-in >> Fan-out



Forward vs. Backward Chaining

Similar fan-in and fan-out:

Backward chaining if

- Interested in only one of many possible conclusions
- Interested in only a general conclusion ("carnivore")
- Facts not gathered yet, only gather useful facts

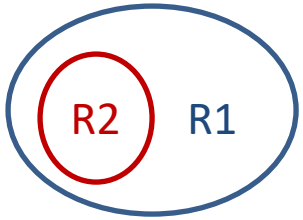
Forward chaining if

- Animal disappeared, cannot gather new facts

Conflict Resolution Strategies

Rule ordering based on:

- **Priority list**
- **Context**: Groups of rules, only one group active at any time
- **Specificity**: Conditions of R1 & R2: Use R1



- **Data**: Prioritize assertions, use triggered rule with highest priority assertion in conditions list
- **Size**: Use triggered rule with longest list of conditions
- **Recency**: Use least recently used rule

Learning Outcomes of this Lecture

- Can define what an expert system is (and know various alternative terms, e.g., knowledge base)
- Describe difference between statistical ML models and rule-based decision systems
- Know terminology of rule-based systems
- Understand how the working memory is used and changed by instantiating rules
- Can describe forward & backward chaining, including drawing a circuit visualization
- Understand pro's and con's of forward & backward chaining
- Know when & how to use conflict resolution strategies