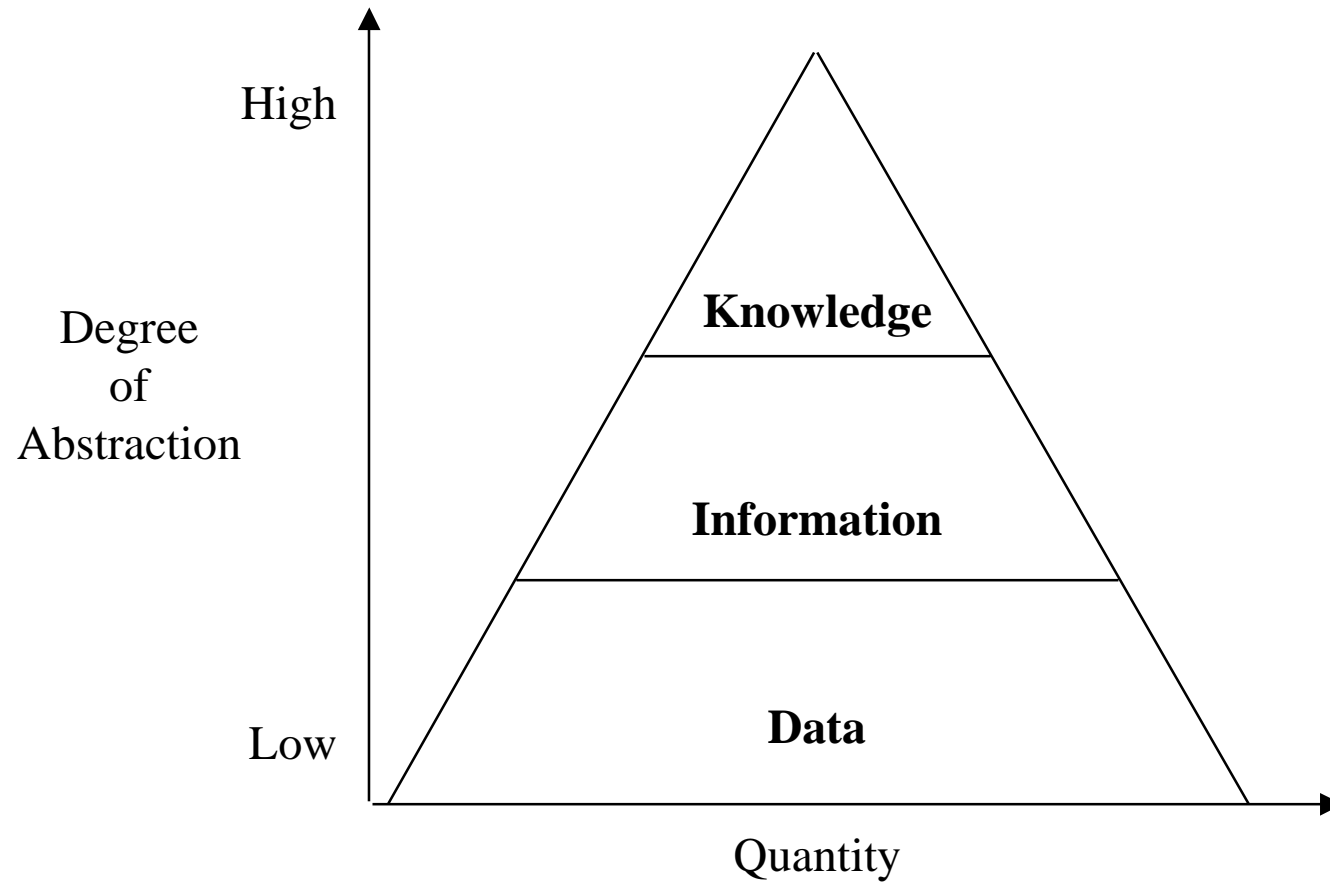


Expert Systems

11/13/02

Data, Information, and Knowledge



Uses of Knowledge in AI

- Knowledge consists of facts, concepts, theories, heuristic methods, procedures, and relationships
- Knowledge is also information organized and analyzed for understanding and applicable to problem solving or decision making
- *Knowledge base* - the collection of knowledge related to a problem (or opportunity) used in an AI system
- Typically limited in some specific, usually *narrow*, subject area or *domain*
- The *narrow domain* of knowledge, and that an AI system involves some *qualitative aspects* of decision making, are critical for AI application success

Expert Systems

- A computer system that embodies the specialized knowledge of one or more human experts; and uses that knowledge to solve problems
- A computer program that contains both declarative knowledge (facts about objects, events and situations) and procedural knowledge (information about courses of action) to emulate the reasoning processes of human experts in a particular domain

History

- GPS (General-purpose Problem Solver)
- DENDRAL
- MYCIN
- ES Shells

Expertise

- Expertise : proficiency in a specialized domain
 - high volume of facts about the problem area
 - (including rare facts)
 - theories about the problem area
 - simplification of complex situations
 - general strategies for problem-solving in this area
 - standard and heuristic procedures for problem-solving

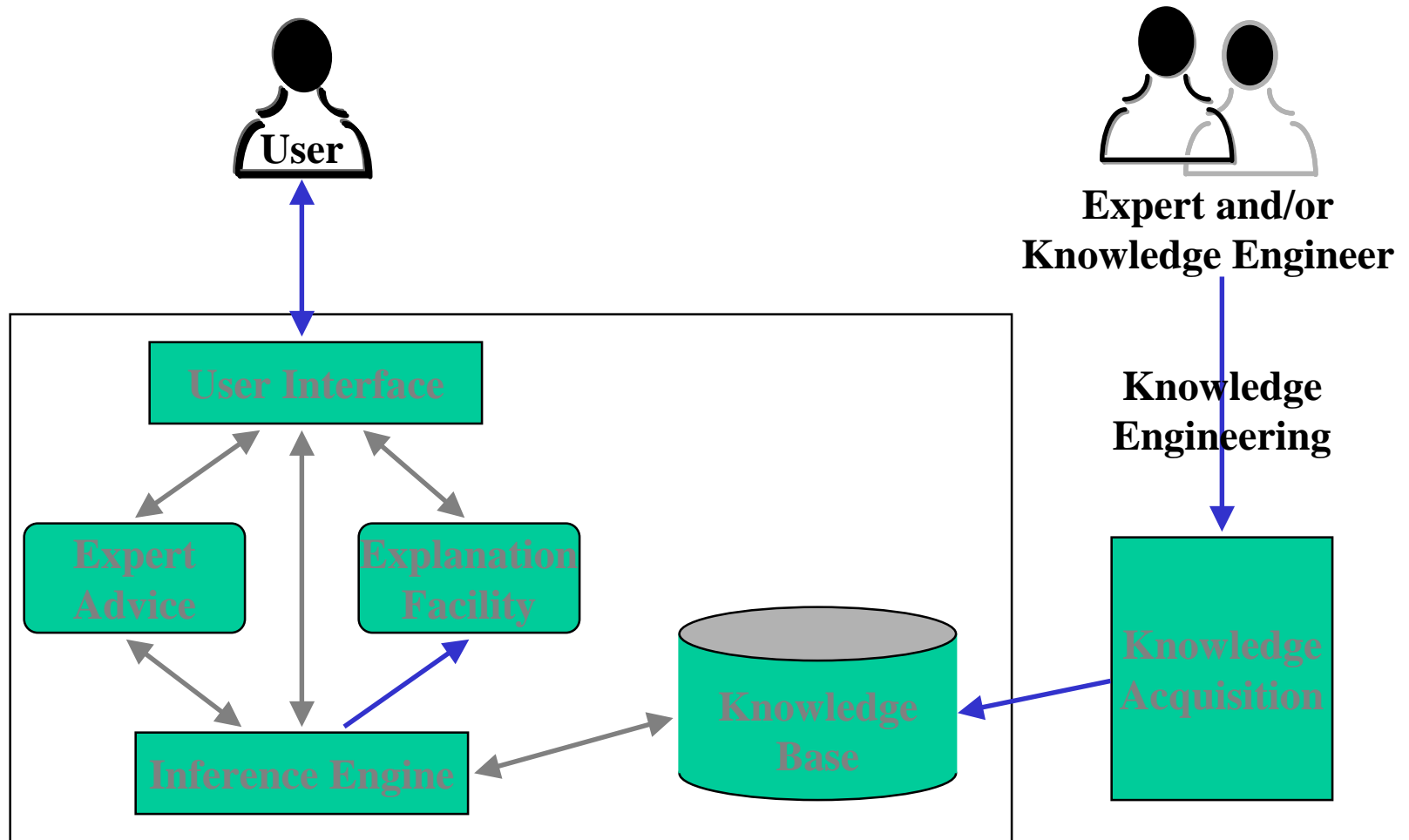
Experts

- Expert : someone who has gained a high level of expertise
 - recognize & formulate the problem
 - solve the problem quickly and properly
 - explain the solution
 - learn from experience
 - restructure their knowledge
 - know when to break rules
 - determine relevance of information
 - be aware of own limitations

Human Expert Characteristics

- Solve problems quickly and accurately
- Explain what they do (and how they do it)
- Judge own conclusions
- Know when stumped
- Communicate with other experts
- Learn
- Transfer knowledge
- Use tools to support decisions
- Knowledge is a major resource
- Important to capture knowledge from a few experts
- Experts become unavailable -> knowledge not available
- Better than books and manuals

Components of an Expert System



Knowledge Engineering

- Acquisition
 - Acquiring knowledge from human experts, books, documents (typically in the form of facts & rules)
- Validation
 - Using test cases to verify quality of knowledge acquired
- Representation
 - Organizing the acquired knowledge into a Knowledge Base
- Inferencing
 - Developing the software to enable inferences to be made using the acquired knowledge
- Explanation & Justification
 - Giving user access to the knowledge - typically via:
 - WHY information is required from the user
 - HOW a particular conclusion was reached

Knowledge Base

- contains the knowledge necessary for understanding, formulating and solving problems
- includes facts about a specific subject area (called a domain). Facts could include definitions, relationships, measurements, probabilities, observations, constraints, and hypotheses
- includes rules of thumb (called heuristics) describing the reasoning procedures by which an expert uses facts to arrive at conclusions

Inference Engine

- the “brains” of the expert system
- evaluates and manipulates the facts and rules in a knowledge base to make associations and inferences resulting in a recommended course of action for the user
- two basic strategies used to create inference chains: backward chaining (goal-driven) and forward chaining (applying rules to facts)

Explanation Facility

- Expert systems are able to provide some explanation for the conclusions they reach
- The explanation component can interactively answer questions like:
 - Why was a certain question asked?
 - How was a certain conclusion reached?
 - Why was a certain alternative rejected?
 - What is the plan to reach the solution?

Knowledge Acquisition

- Knowledge acquisition is the accumulation, transfer, and transformation of problem-solving expertise from a knowledge source to a knowledge base
- Potential sources of knowledge include human experts, textbooks, databases, special research reports, and pictures
- A knowledge engineer works with experts to capture their knowledge and incorporate it into the knowledge base

Application Areas

- Interpretation
- Prediction
- Diagnosis
- Design
- Planning
- Monitoring
- Debugging
- Repair
- Instruction
- Control

ES Shells and Languages

- Shells
 - EMYCIN
 - VP-Expert
 - Crystal
 - EXSYS
 - ...
- Development environments
 - KEE (Knowledge Engineering Environment)
 - Nexpert
 - OPS5
- Programming languages
 - C
 - LISP (List Processing)
 - Prolog

Benefits

- Increased efficiency
- Increased effectiveness
- Expertise when and where required
- Reliability
- Can cope with incomplete / uncertain information
- Provision of training

Limitations

- Knowledge is not always available
- Knowledge elicitation/acquisition is complex
- Extracted knowledge may vary from different experts
- ES only works well in a limited domain
- Difficult to independently check conclusions
- Experts may use unfamiliar jargon
- Good knowledge engineers are rare
- Difficult to build user trust
- No guarantee advice will always be appropriate
- ES may not always be able to come up with advice

Types of Reasoning

- Deductive
- Inductive
- Analogical
- Formal

Deductive Reasoning

- A process in which general premises are used to make a specific inference
- Typically involves three parts:
 - a major premise
 - a minor premise
 - a conclusion
- For example:
 - MAJOR PREMISE: *I don't teach on public holidays*
 - MINOR PREMISE: *Christmas Day is a public holiday*
 - CONCLUSION: *I will not teach on Christmas Day*

Inductive Reasoning

- A process in which a number of premises are used to draw some general inference
- There is no guarantee that the inference is true, unless all the relevant premises are checked - thus there will always be an element of uncertainty
- For example:
 - PREMISE: *An opossum is an animal & it has fur*
 - PREMISE: *A wombat is an animal & it has fur*
 - PREMISE: *A mouse is an animal & it has fur*
 - CONCLUSION: *All animals have fur*

Analogical Reasoning

- A process in which an inference is made by drawing on similar past experience
- The more similar the past experience to the present one, the more confident we can be of the likely outcome
- For example:
 - PRESENT: The grass is getting quite long
 - PAST: When the grass got very long, it was hard to cut
 - CONCLUSION: I should cut the grass soon - before it gets hard to cut

Formal Reasoning

- A process in which an inference is made by using the rigorous application of formal logical structures and rules
- Modus Ponens: Given the rule “A implies B”, if A is true, so will B be true
- Modus Tollens: Given the rule “A implies B”, if B is false, so will A be false

Inferencing with Rules

- Backward Chaining: [Goal Driven]
 - Start with a goal. Look for a rule that has that goal as its conclusion. Check the premise of this first rule. Check the assertions (facts) first. If that fails, find another rule whose conclusion is the same as the premise of the first rule. Try to satisfy this second rule. Continue until the first rule is satisfied, or all possibilities have been checked.
- Forward Chaining: [Data Driven]
 - Start from the assertions (facts) and try to infer conclusions. If a new conclusion can be inferred, then assert it. Using the now expanded assertion base, try to infer some more conclusions. Continue until all the possible conclusions have been inferred.

Backward Chaining Example

- Consider the following question:
 - Should an investor invest in IBM stock?
- The Facts:
 - she is 25 years old
 - she has \$10,000 to invest

Backward Chaining Example (cont'd)

- The following variables are involved:
 - A. Have \$10,000
 - B. Younger than 30
 - C. Education at college level
 - D. Annual income $>$ \$40,000
 - E. Invest in securities
 - F. Invest in growth stocks
 - G. Invest in IBM stock

Backward Chaining Example (cont'd)

- The Rules:
 - R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
 - R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
 - R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
 - R4: IF she is younger than 30,
THEN she has a college degree
 - R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

Backward Chaining Example (cont'd)

The Starting Point:

- Goal: Should she invest in IBM stock?
- only rule R5 satisfies the goal as its conclusion

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN **the stock should be IBM**

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

Backward Chaining Example (cont'd)

Step 1:

- try to *accept* or *reject* our Goal
 - establish if “she wants to invest in a growth stock” is true
- if we check our assertion base (i.e. the given and asserted facts), we see that:
 - “she is 25 years old” and “she has \$10,000 to invest” are both true
 - rule R5 cannot be fired (invoked) yet

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF **she wants to invest in a growth stock**,
THEN the stock should be IBM

given facts

- **she is 25 years old**
- **she has \$10,000 to invest**

asserted facts

Backward Chaining Example (cont'd)

Step 2:

- to establish if “she wants to invest in a growth stock” is true:
- note that “she wants to invest in a growth stock” is the conclusion of both rule R2 and rule R3
- suppose we look at the premises of rule R2 (arbitrarily) first

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

Backward Chaining Example (cont'd)

Step 3:

- to fire rule R2 requires both premises be true
- but “her annual income is at least \$40,000” is neither a given fact nor is it the conclusion of any rule
- either more information is required (ie a fact about “her annual income is at least \$40,000” must be established)
- or we can return to rule R3
- [this backing away from one rule and looking at an alternative is called backtracking]

R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities

R2: IF **her annual income is at least \$40,000**
and **she has a college degree**,
THEN she should invest in growth stocks

R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks

R4: IF she is younger than 30,
THEN she has a college degree

R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- **she is 25 years old**
- **she has \$10,000 to invest**

asserted facts

Backward Chaining Example (cont'd)

Step 4:

- to fire rule R3 requires both “she is younger than 30” and “invests in securities” be true
- we know “she is younger than 30” is true - it is a given fact (“she is 25 years old”)
- to establish if “invests in securities” is true, we note that it is the conclusion for rule R1

- R1: IF she has \$10,000
and has a college degree,
THEN **she should invest in securities**
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF **she is younger than 30**
and **invests in securities**,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- **she has \$10,000 to invest**

asserted facts

Backward Chaining Example (cont'd)

Step 5:

- to fire rule R1, we require “she has \$10,000” and “has a college degree” to be true
- “she has \$10,000” is true - it is a given fact
- to test “has a college degree”, we note that it is the conclusion of rule R4

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

Backward Chaining Example (cont'd)

Step 6:

- to fire rule R4, we require “she is younger than 30” to be true
- “she is younger than 30” is true - it is a given fact (“she is 25 years old”)
- therefore rule R4 fires and “has a college degree” becomes a fact and is added to the assertion base

- R1: IF **she has \$10,000**
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF **she is younger than 30**
and invests in securities,
THEN she should invest in growth stocks
- R4: IF **she is younger than 30**,
THEN **she has a college degree**
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- **she is 25 years old**
- **she has \$10,000 to invest**

asserted facts

- **she has a college degree**

Backward Chaining Example (cont'd)

Step 7:

- moving forward again along the rule chain:
- we can use our newly asserted fact to fire rule R1 to establish “she should invest in securities” as a fact

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree
- she should invest in securities

Backward Chaining Example (cont'd)

Step 8:

- moving forward again along the rule chain:
- we can now fire rule R3 to assert “she should invest in growth stocks” as a fact

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree
- she should invest in securities
- she should invest in growth stocks

Backward Chaining Example (cont'd)

Step 9:

- moving forward again along the rule chain:
- we can now fire rule R5 to assert “she should invest in IBM stock” as a fact

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN **the stock should be IBM**

given facts

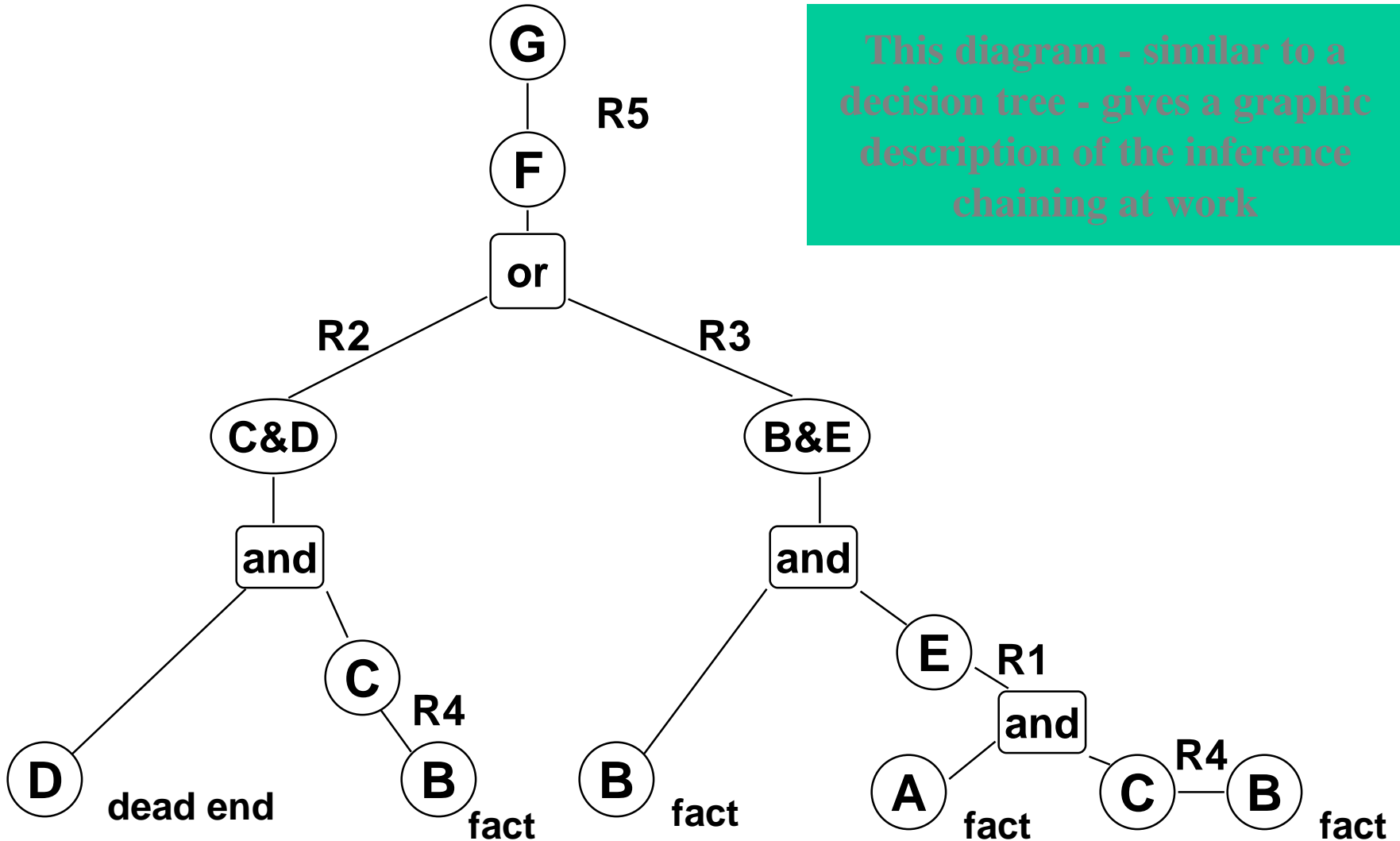
- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree
- she should invest in securities
- she should invest in growth stocks
- the stock should be IBM

Inference Tree

This diagram - similar to a decision tree - gives a graphic description of the inference chaining at work



Forward Chaining Example

- The Facts:
 - she is 25 years old
 - she has \$10,000 to invest
- The Rules:
 - R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
 - R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
 - R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
 - R4: IF she is younger than 30,
THEN she has a college degree
 - R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM
- What conclusions can we draw?

Forward Chaining Example

The Starting Point:

- Known: “she has \$10,000” and “she is younger than 30” are true
- rule R1 (arbitrarily) contains “she has \$10,000” in its IF side
- rule R1 includes “she should invest in securities” in its conclusion (THEN side)

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

Forward Chaining Example

Step 1:

- attempt to verify “she should invest in securities”
- since “she has \$10,000” is known (fact)
- try to find “she has a college degree” in the assertion base - it’s not there
- because “she has a college degree” is not asserted, find a rule with “she has a college degree” in the THEN side
- this is rule R4

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

Forward Chaining Example

Step 2:

- test rule R4
- “she has a college degree” is true because “she is younger than 30” (fact) is in the assertion base
- assert “she has a college degree” as true

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree

Forward Chaining Example

Step 3:

- rule R1 now fires and “she should invest in securities” is asserted
- this leads to rule R3 where “she should invest in securities” is in the IF side

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree
- she should invest in securities

Forward Chaining Example

Step 4:

- since “she is younger than 30” (fact) is in the assertion base
- and “she should invest in securities” (asserted) is in the assertion base
- rule R3 fires and “she should invest in growth stocks” is asserted

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN the stock should be IBM

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree
- she should invest in securities
- she should invest in growth stocks

Forward Chaining Example

Step 5:

- rule R5 has “she should invest in securities” in its IF side
- since “she should invest in securities” is in the assertion base, rule R5 fires
- “the stock should be IBM” (conclusion) is established as true
- Recommendation: is to invest in IBM stock

- R1: IF she has \$10,000
and has a college degree,
THEN she should invest in securities
- R2: IF her annual income is at least \$40,000
and she has a college degree,
THEN she should invest in growth stocks
- R3: IF she is younger than 30
and invests in securities,
THEN she should invest in growth stocks
- R4: IF she is younger than 30,
THEN she has a college degree
- R5: IF she wants to invest in a growth stock,
THEN **the stock should be IBM**

given facts

- she is 25 years old
- she has \$10,000 to invest

asserted facts

- she has a college degree
- she should invest in securities
- she should invest in growth stocks
- **the stock should be IBM**