Chapter 7

Knowledge Representation

（知识表示）

关于知识

信息社会是
知识驱动的社会

知识的价值

工业时代 —— 钢铁

信息时代 —— 知识

知识是一种重要的资源。传统的“生产要素”（土地、劳动力和资本）已经变为次要的因素。只要有知识，就可以很容易获得这些要素。

数据、信息、知识

数据(data)

信息(information)

知识(knowledge)

是三个经常遇到的且联系非常密切的词，虽然意义上稍有不同，但它们经常被当做同义词互换使用，由此导致了持久的混乱。

数据 数据是我们每时每刻感觉到的大量的没有经过解释的信号。计算机里装满了数据。

信息 信息是具有意义的数据。一位汽车司机，红色的交通灯不仅仅是一个具有某种颜色的物体的信号，而应解释为一个停车的指示。一个来自太空的外星人，不可能把红色交通灯理解为停车。数据相同，但信息不同。

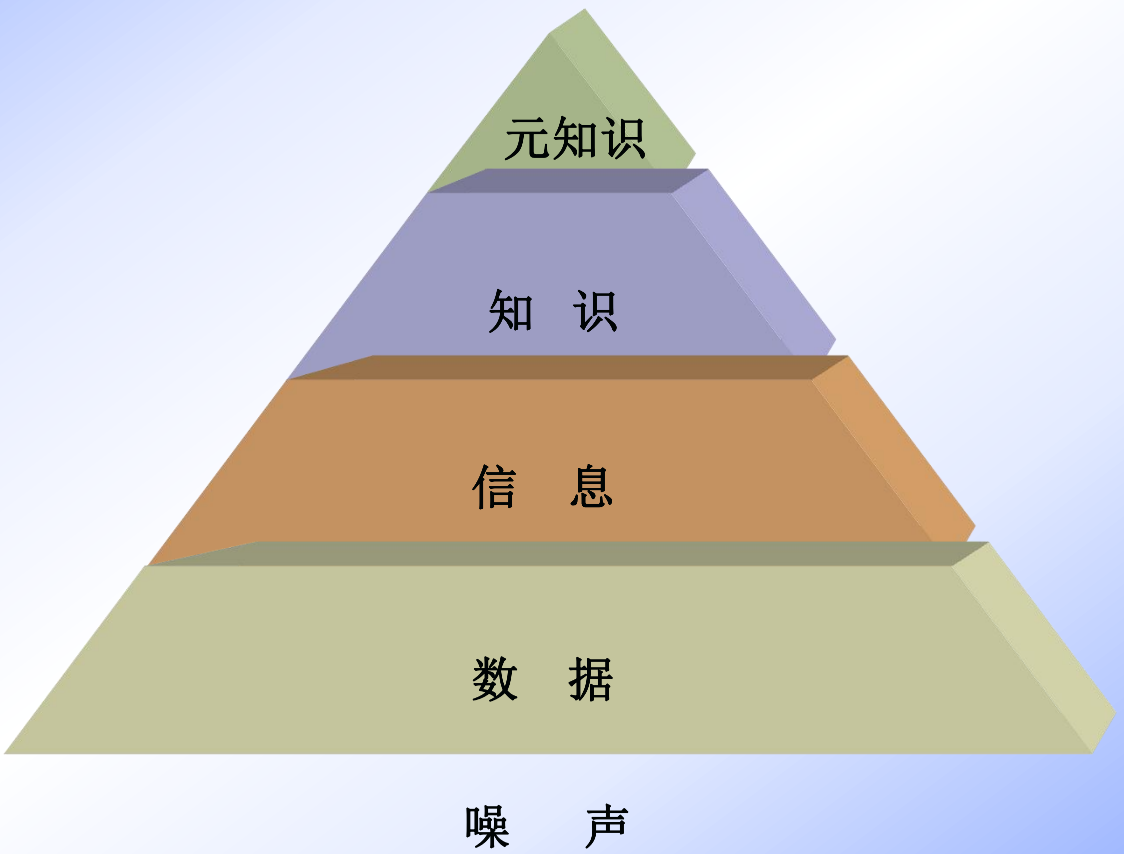
知识 知识增加了两个不同的方面：第一，目的感，因为知识是用来达到一个目标的。第二，再生能力，因为知识的主要功能之一就是产生新的信息。

表1 数据、信息和知识的区别

术 语	特 征	例 子
数据	未经处理的原始材料	…——…
信息	有意义的数据	SOS
知识	·具有一定目的的信息 ·产生一定的行动	紧急警报—> 开始营救行动

- 知识紧密地依赖语境(context)。一个人的知识可能是另外一个人的数据。数据、信息和知识之间的分界线并不是很清晰的，因为它们与所使用的语境有关。

知识的层次结构



明确的知识和不言而喻的知识

- 大部分知识是不言而喻的,其拥有者不能清晰描述的，不易解释并无法正式表述在书中的。
- 但是，这是一种“背景”能力，它是无意识的，是在行动中的知识。它起源于完成其他人类任务所获得的经验。
- 图2-1说明了四种知识生产的模式：

四种知识生产的模式

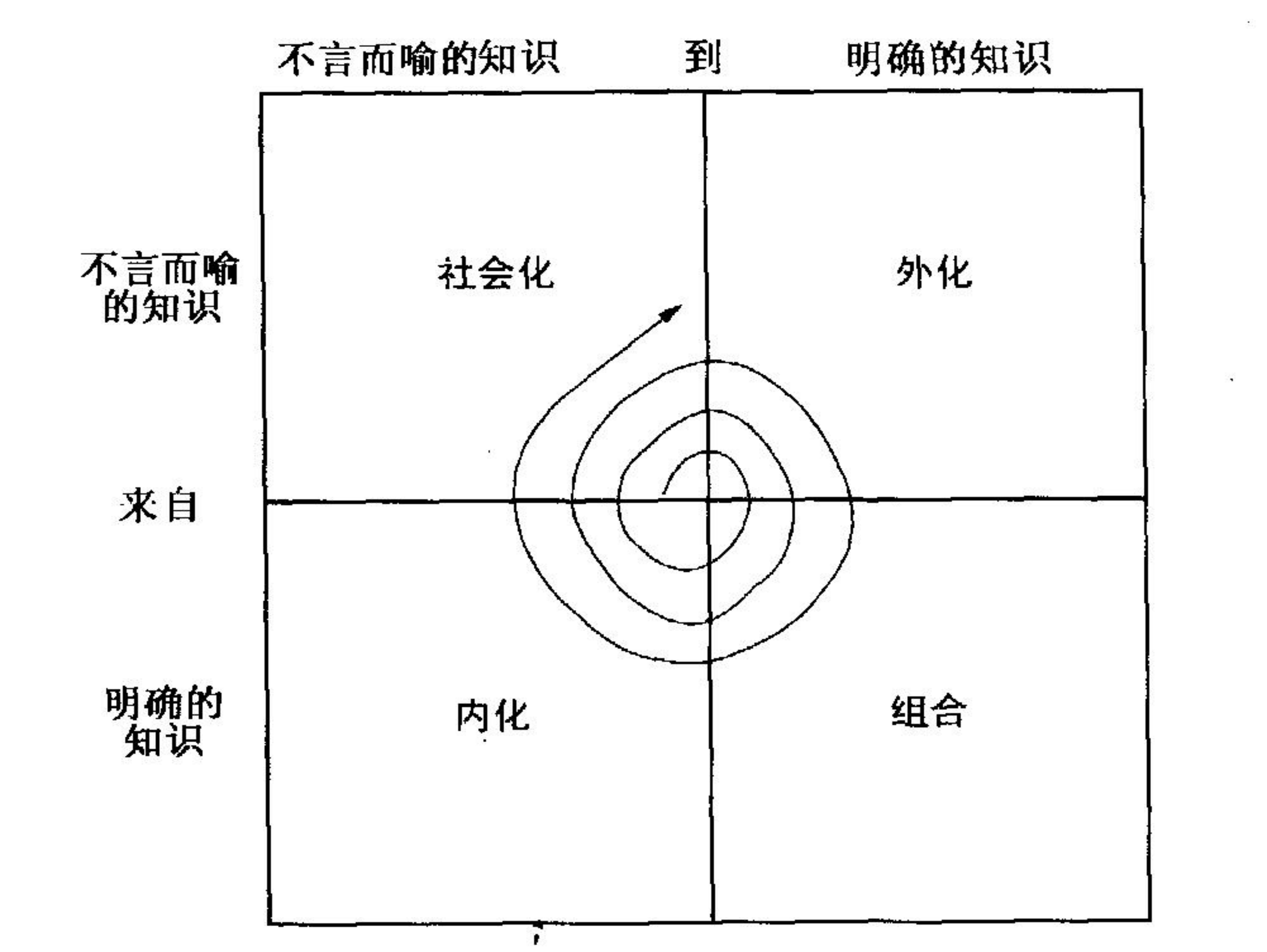


图2—1 知识创建动态模型

1)从不言而喻的知识到不言而喻的知识(＝社会化)；人们可以通过互相展示，而不是通过对话互相教会关于某主题的内容。

2)从不言而喻的知识到明确的知识(＝知识外化)：知识密集型的活动通过写在纸上而被阐明，并形成正式的产品等。

3)从明确的知识到明确的知识(＝组合)：通过集成不同的明确的知识片断而产生知识。

4)从明确的知识到不言而喻的知识(＝内化)：频繁地完成一项任务导致不假思索就成功地完成一项任务的个人状态。

知识工程——把不言而喻的知识转化成明确的知识

- 知识创造需要不断地进行这四种形式的知识生产过程。知识管理的目的非常有利于并刺激这些知识过程，所以螺旋式动态上升的知识便出现了。
- 在这一观点下，知识工程是一个在“外化”方面特别有用的方法学，即把不言而喻的知识转化成明确的知识。这是知识工程学的独一无二的特征。

知识的定义

（难以给出明确的定义只能从不同侧面加以理解）

- **Feigenbaum**：知识是经过消减、塑造、解释和转换的信息。
- **Bernstein**：知识是由特定领域的描述、关系和过程组成的。
- **Hayes-roth**：知识是事实、信念和启发式规则。
- 知识库的观点：知识是某领域中所涉及的各有关方面的一种符号表示。

知识的种类

- 事实性知识：采用直接表示的形式。

  如：凡是猴子都有尾巴。

- 判断性知识
- 过程性知识：描述做某件事的过程。

  如：电视维修法。

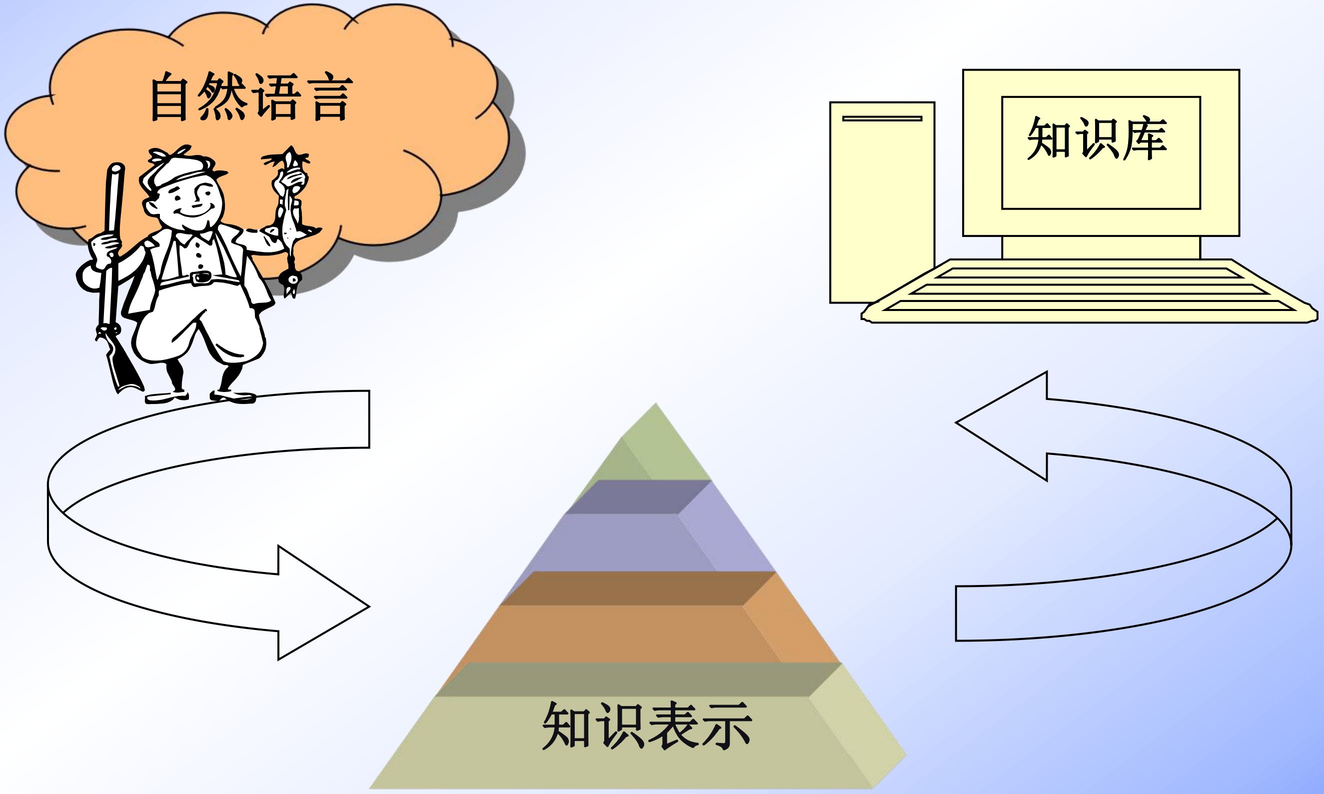
- 对象级知识，或称为领域相关的知识。
- 元知识：有关知识的知识。最重要的元知识是如何使用知识的知识，如何从知识库中找到想要的知识。

知识的要素

- 事实：事物的分类、属性、事物间关系、科学事实、客观事实等。（最低层的知识）
- 规则：事物的行动、动作和联系的因果关系知识。（启发式规则）。
- 控制：当有多个动作同时被激活时，选择哪一个动作来执行的知识。（技巧性）
- 元知识：高层知识。怎样使用规则、解释规则、校验规则、解释程序结构等知识。

关于知识表示

什么是知识表示？



知识表示目的与思路

- 知识表示的目的

  ——使用知识。它是问题求解和专家系统的基础。

- 知识表示遵循思路

自然语言表示 → 格式化表示 → 计算机语言表示

谓词逻辑
产生式规则
与或图
状态空间
语义网络等

人工智能语言
（如Prolog语言）
通用程序设计语言
（如C、C++）

如果有毛发或者产奶，那么它是哺乳动物；

如果吃肉，那么它是食肉动物；如果有犬齿、有爪、眼视前方，那么它也是食肉动物；如果是哺乳动物、食肉动物、黄褐色、有黑色条纹，那么它是老虎。

自然语言描述知识

产生式规则的基本形式：

If P then Q

或者**P→Q**

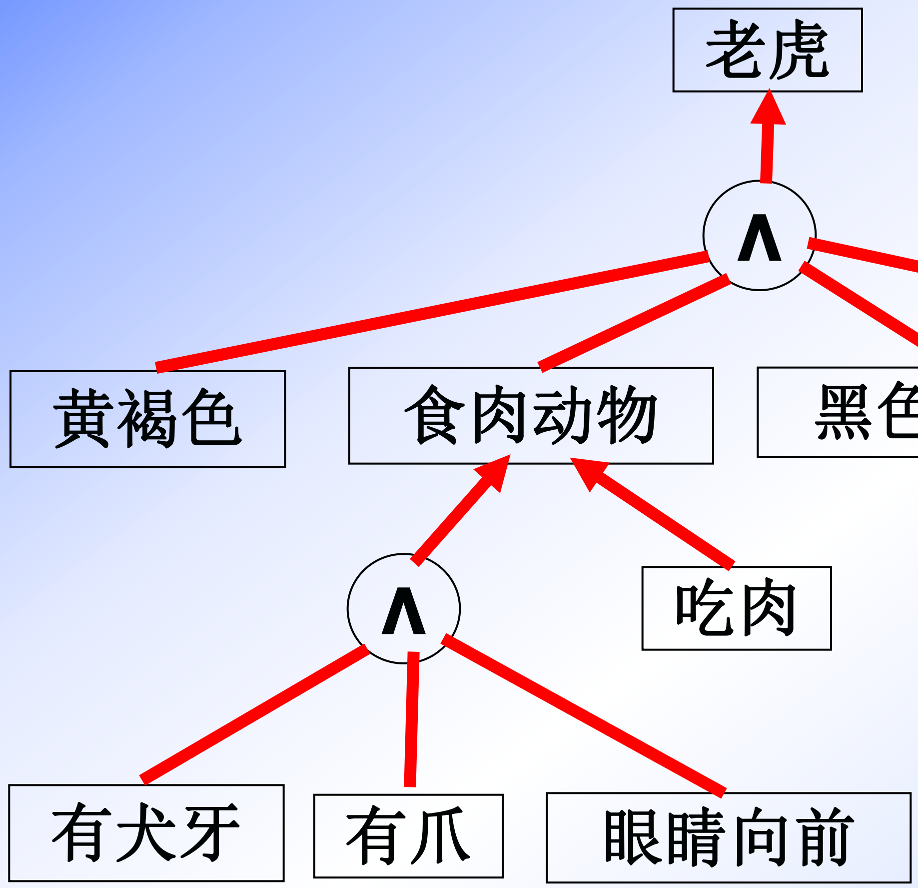
if 有毛发或者产奶 **then** 它是哺乳动物；

if 吃肉 **then** 它是食肉动物；

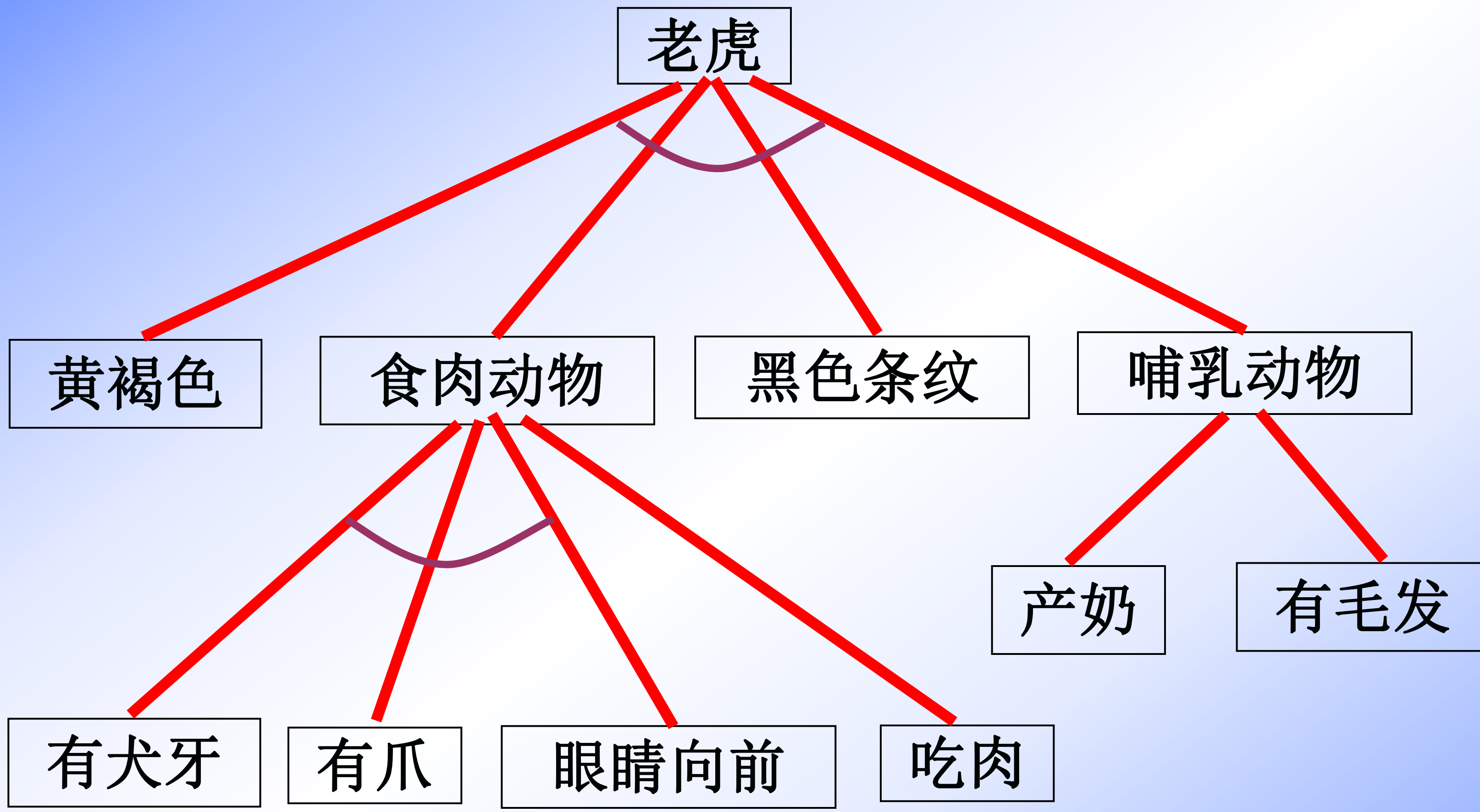
if 有犬齿，且有爪，且眼视前方 **then** 它是食肉动物；

if 是哺乳动物，且是食肉动物，且是黄褐色，且有黑色条纹 **then** 它是老虎。

产生式规则表示知识



产生式规则表示知识的网络



与或图表示知识

定义如下谓词：

positive(X)表示该动物具有特点**X;**

negative(X)表示该动物不具有特点**X;**

It_is(X)表示该动物属于**X**类别**;**

Animal_is(X)表示该动物的名字叫**X.**

用Prolog语言表示知识（1）

It_is(“哺乳动物”):-positive(“有毛发”)

It_is(“哺乳动物”):-positive(“产奶”)

It_is(“食肉动 物”):-positive(“吃肉”)

It_is(“食肉动物”):-positive(“有犬齿”), positive(“有爪”)，positive(“眼视前方”)

Animal_is(“老虎”):-It_is(“哺乳动物”)，It_is(“食肉动物”)，positive(“黄褐色”)，positive(“有黑色条纹”)

用Prolog语言表示知识（2）

[例] 在专家系统MYCIN中有一条产生式：

if 微生物的染色斑是革兰氏阴性

微生物的形状呈杆状

病人是中间宿主

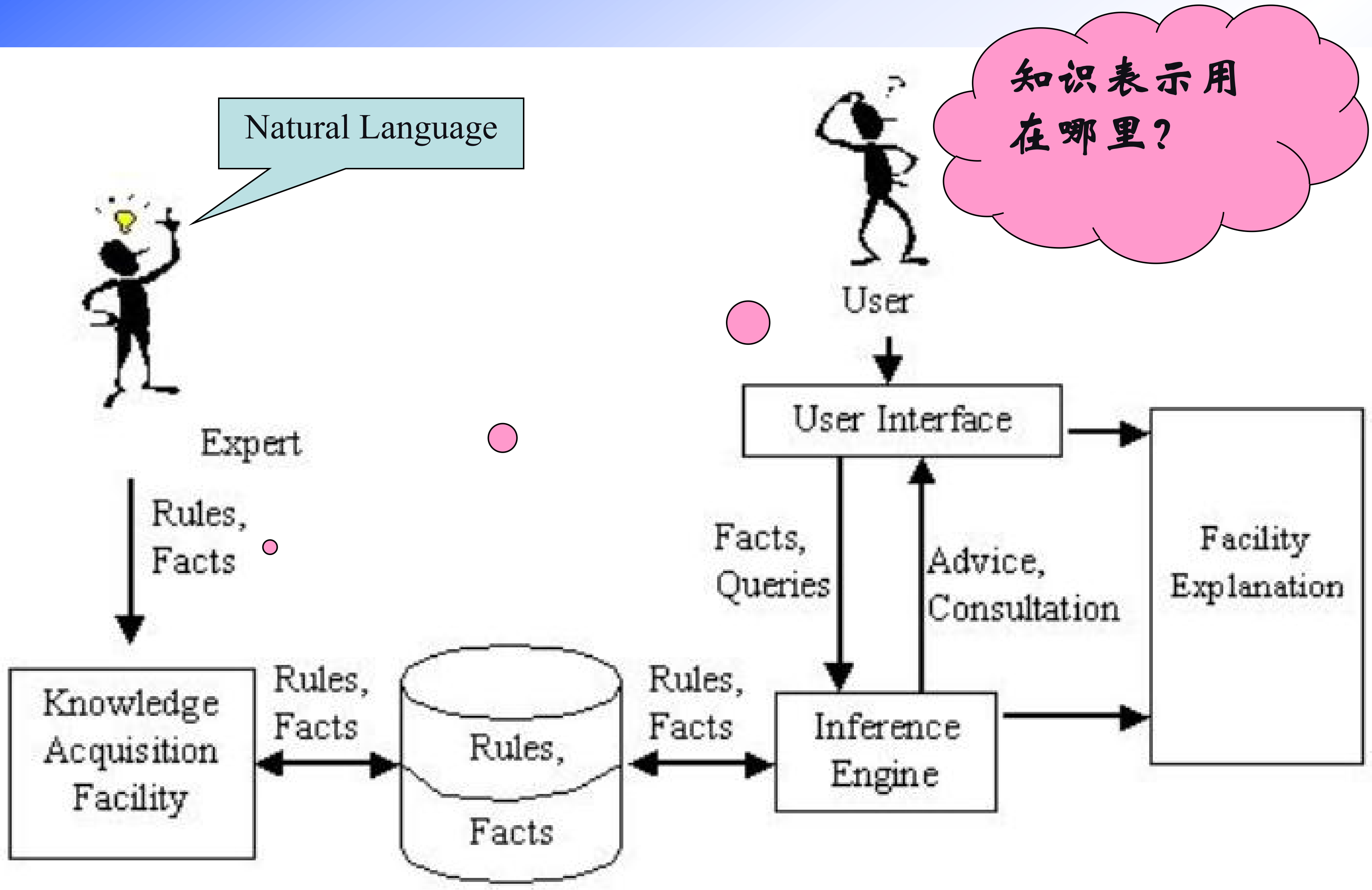
then 该微生物是绿脓杆菌，置信度为0.6

知识具有领域相关性！

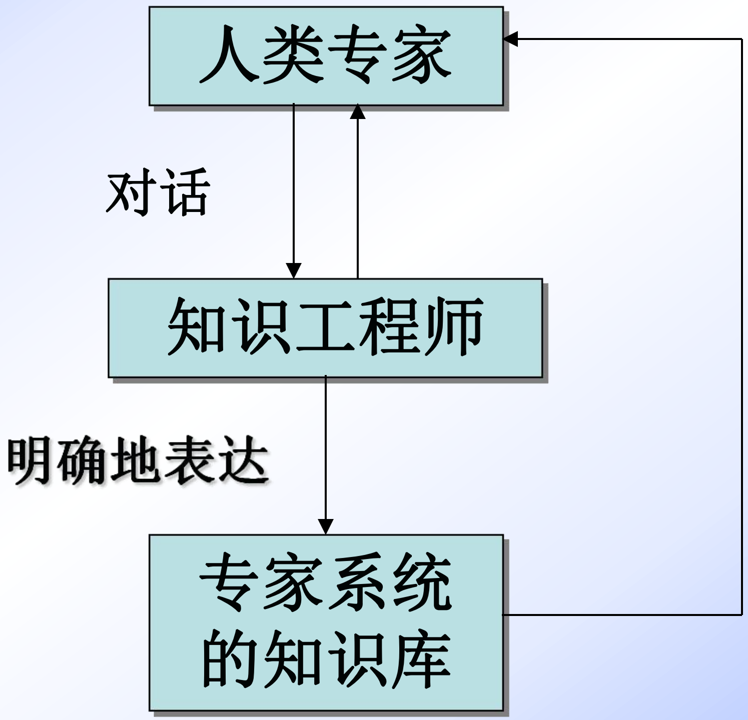
- 上例中规则的LISP表达式：

```
PREMISE:  ($ AND (SAME CNTXT GRAM GRAMNEG)
                 (SAME CNTXT MORPH ROD)
                 (SAME CNTXT AIR AEROBIC))
ACTION:   (CONCLUDE CNTXT CLASS BACTEROID TALLY 0.6)
```

知识表示在软件系统开发中的作用


Natural Language
知识表示用
在哪里？
User
Expert
User Interface
Rules,
Facts
Facts,
Queries
Advice,
Consultation
Facility
Explanation
Knowledge
Acquisition
Facility
Rules,
Facts
Rules,
Facts
Rules,
Facts
Inference
Engine

知识获取过程中知识表示的地位



7.0 Issues in knowledge Representation

Historical perspective（观点） of Representation:

- **a knowledge base is described as a *mapping* *between* *the objects and relations in* a problem domain and the computational objects and relations of a program.**

- The results of inferences（推理结果） in the knowledge base are assumed to correspond to（对应） the results of actions （行为结果） in the world.
- The computational objects, relations and inferences available(可用) to programmers are mediated（中介）by the knowledge representation language.

7.1 A Brief History of AI Representational Schemes

7.1.1 Associationist Theories of Meaning

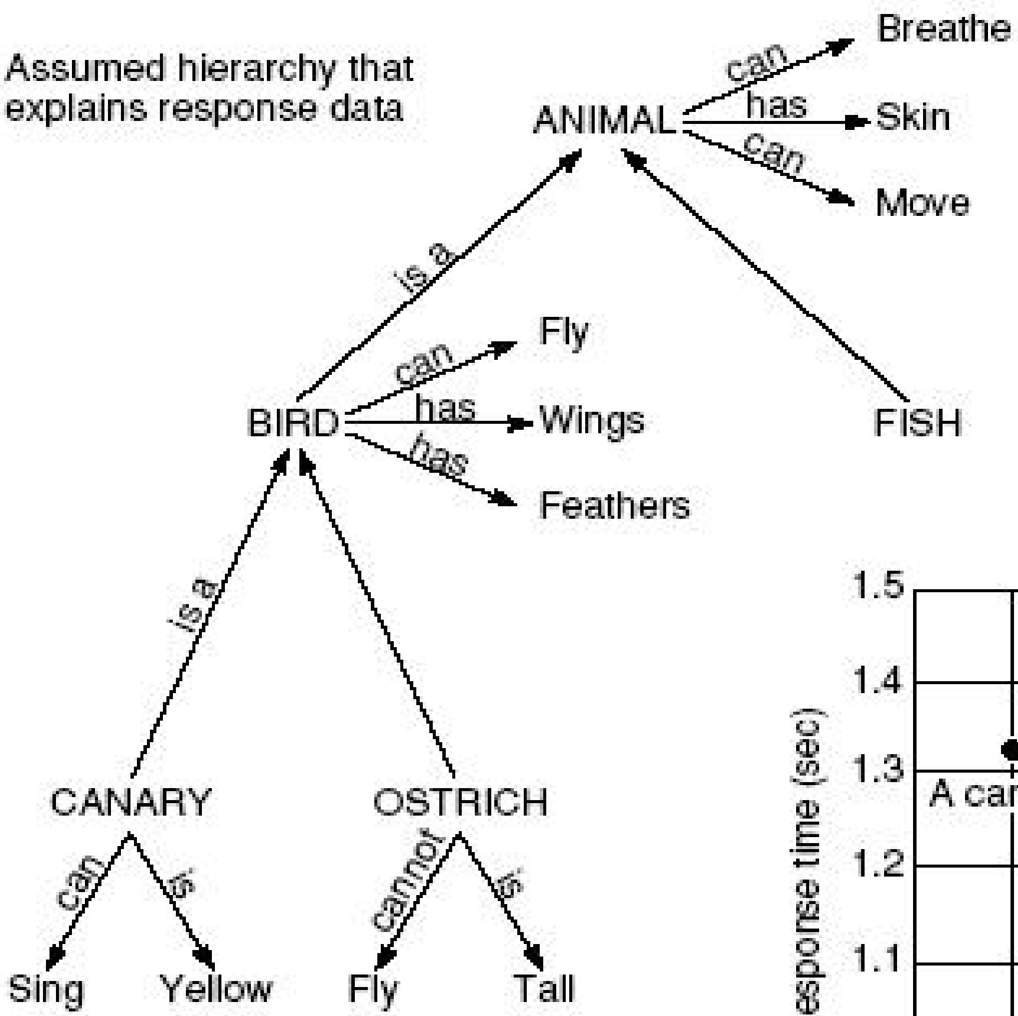
- The major concern of logic is the development of formal representation languages with sound and complete inference rules.

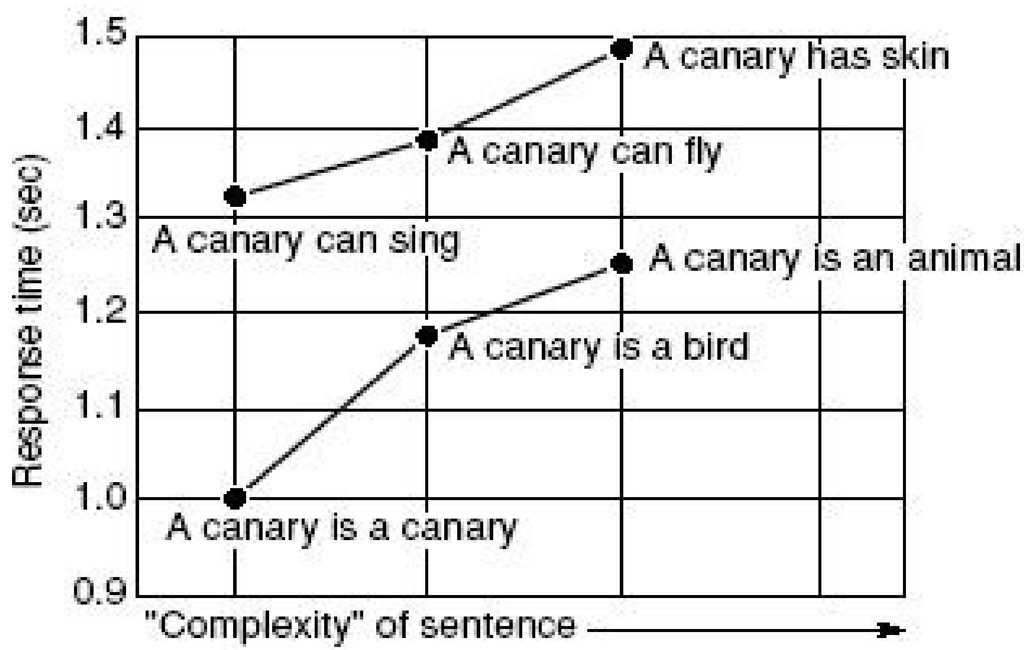
- An alternative line of research has grown out of the efforts of psychologists（心理学家）and linguists to characterize the nature of human understanding.
- This work is less concerned with establishing a science of correct reasoning than with describing the way in which humans acquire, associate, and use knowledge.

- **Associationist（联想）theories define the meaning of an object in terms of a network of associations with other objects.**

- **Human also organize their knowledge hierarchically, with information kept at the highest appropriate（合适的） levels of the taxonomy（分类法）.**

human information storage and response times





Convert the semantic network in Figure 7.1 into predicate calculus statements.

$$\forall x Canary(x) \rightarrow (Sings(x) \wedge Yellow(x) \wedge Bird(x))$$

$$\forall x Ostrich(x) \rightarrow (Bird(x) \wedge \neg Flies(x) \wedge Tall(x))$$

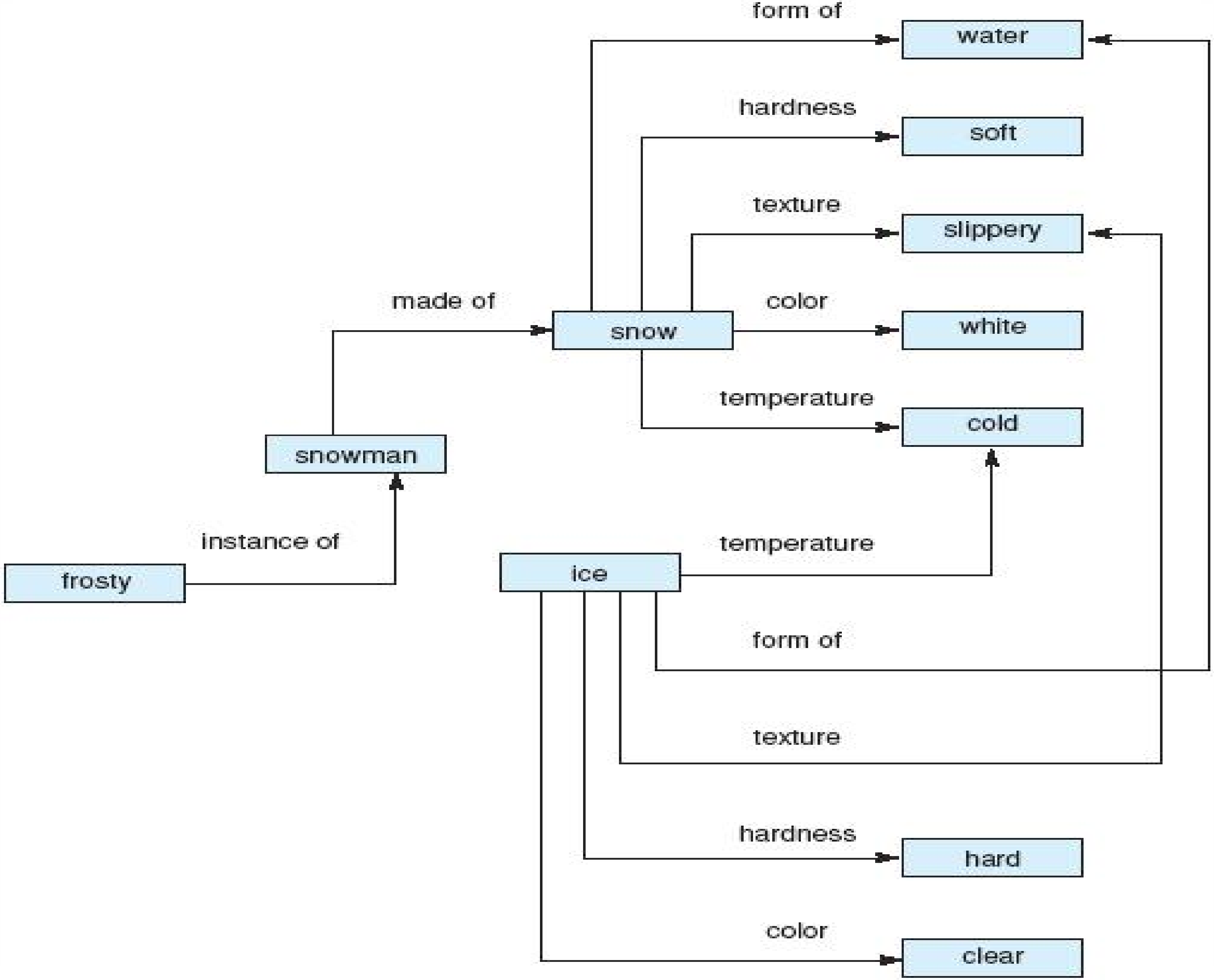
$$\forall x Bird(x) \rightarrow (Flies(x) \wedge hasFeathers(x) \wedge hasWings(x) \wedge Animal(x))$$

$$\forall x Bird(x) \rightarrow \neg Fish(x)$$

$$\forall x Fish(x) \rightarrow Animal(x)$$

$$\forall x Animal(x) \rightarrow (Breathes(x) \wedge Moves(x) \wedge hasSkin(x))$$

- A semantic network（语义网）represents knowledge as a graph
- The nodes correspond to facts or concepts
- The arcs correspond to relations or associations between concepts.


form of
water
hardness
soft
texture
slippery
made of
snow
color
white
temperature
cold
snowman
instance of
frosty
ice
temperature
form of
texture
hardness
hard
color
clear

Convert the network representation in Figure 7.2:

a.) Into predicate calculus statements

b.) Into English statements

Solution:

a.)

$$\forall x Frosty(x) \rightarrow snowman(x)$$

$$\forall x snowman(x) \rightarrow madeOfSnow(x)$$

$$\forall x snow(x) \rightarrow (water(x) \wedge soft(x) \wedge slippery(x) \wedge white(x) \wedge cold(x))$$

$$\forall x ice(x) \rightarrow (water(x) \wedge hard(x) \wedge slippery(x) \wedge clear(x) \wedge cold(x))$$

b.) Frosty is a type of snowman.

A snowman is made of snow.

Snow is a form of water that is soft, slippery, white in color, and cold.

Ice is a form of water that is hard, slippery, clear in color, and cold.

用语义网络表示知识的步骤

（1）确定问题中所有的对象以及各对象的属性。

（2）分析并确定语义网中所论对象间的关系。

（3）根据语义网络中所涉及的关系，对语义网络中的节点和弧进行整理，包括增加节点、弧和归并节点等。

（4）分析检查语义网络中是否含有要表示知识中的所有对象，若有遗漏，则须补全。并将各对象间的关系作为网络中各节点间的有向弧，连接形成语义网络。

（5）根据第（1）步的分析结果，为各对象标示属性。

语义网络表示知识举例

例1. 用语义网络表示下列知识：

（1）树和草都是植物；
（2）树和草是有根有叶的；
（3）水草是草，且长在水中；
（4）果树是树，且会结果；
（5）苹果树是果树的一种，它结苹果。

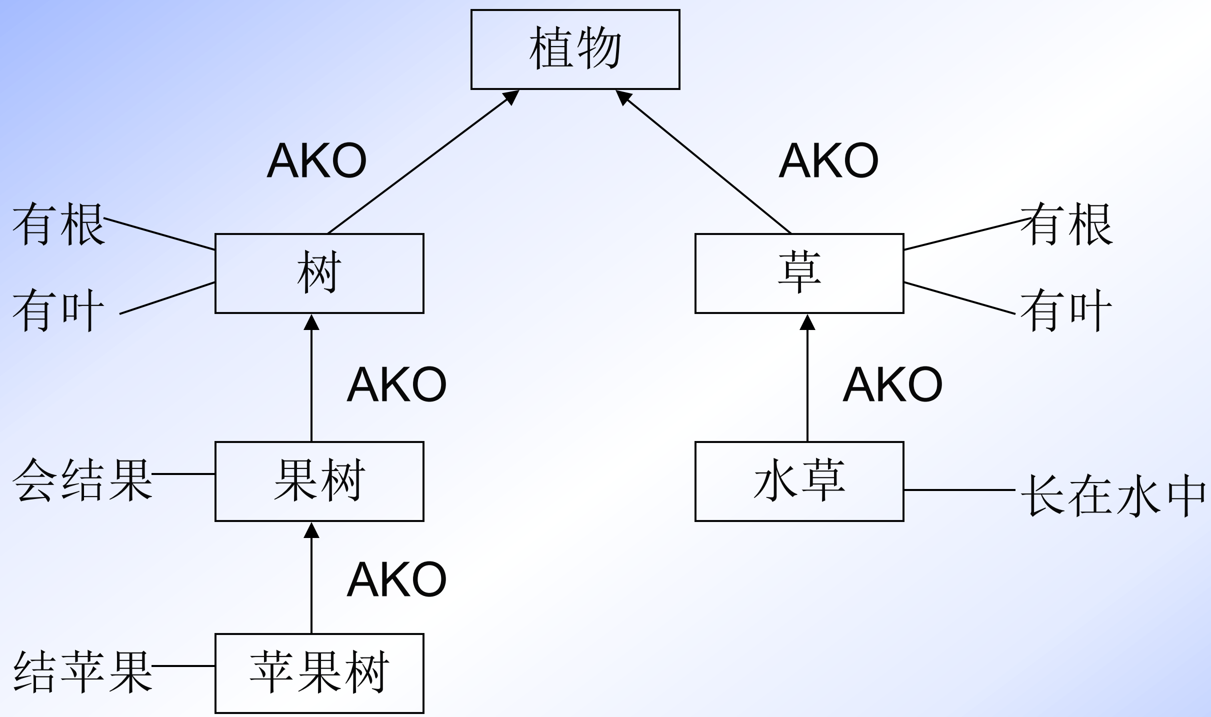
解：（1）问题涉及的对象有植物、树、草、水草、果树、苹果树，共6个对象。

各对象的属性分别为，树和草的属性：有根、有叶；水草的属性：长在水中；果树的属性：会结果；苹果树的属性：结苹果。

（2）树和草与植物间的关系是AKO；水草和草之间的关系是AKO；果树和树之间的关系是AKO；苹果树和果树之间的关系是AKO。

（3）根据信息继承性原则，各上层节点的属性下层都具有，在下层都不再标出，以避免属性信息重复。

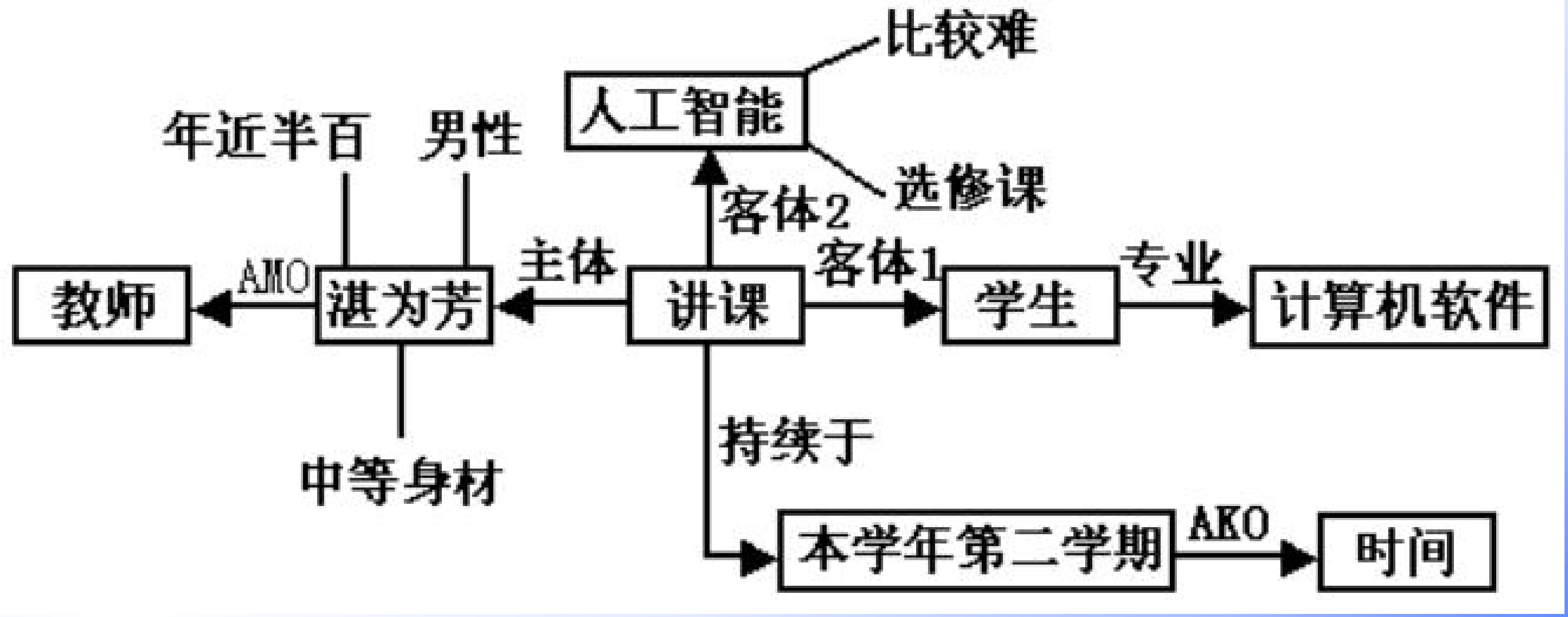
（4）根据上面的分析，共涉及6个对象，各对象的属性以及它们之间的关系已在上面指出，所以语义网络应该是由6个节点构成的有向图。



有关树和草的语义网络

例2. 用语义网络表示下列事实

湛为芳是一位年近半百的男教师，中等身材，他在本学年第二学期给计算机专业学生讲授“人工智能”课程。该课程是一门选修课，比较难。



课堂练习

用语义网络描述下列事实：

苹果树枝繁叶茂，结了很多苹果，有大的，也有小的，有红的，也有绿的。

思考练习题

- 用语义网络表示下面的事实。

（1）每个学生都学习了C++语言。

（2）每个学生都学习了一门程序设计语言。

（3）每个学生都学习了所有的程序设计课程。

（4）猎狗是一种狗，而狗是一种动物。狗除了动物的有生命、能吃食物、有繁殖能力、能运动外，还有以下特点：身上有毛、有尾巴、四条腿；猎狗的特点是吃肉、个头大、奔跑速度快、能狩猎；而狮子狗也是一种狗，它的特点是吃饲料、身体小、奔跑速度慢、不咬人、供观赏。

7.1.2 Early Work in Semantic Net

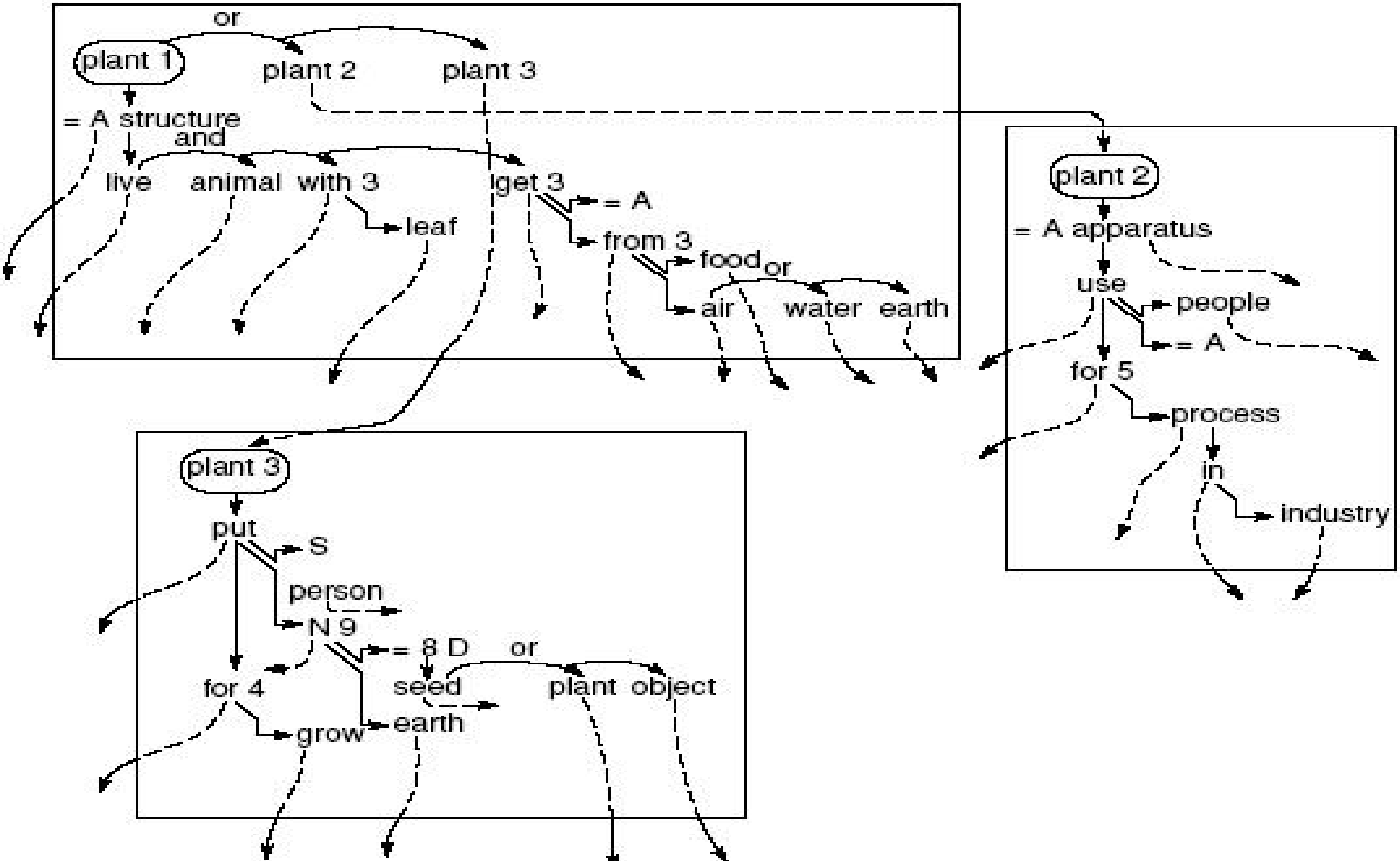
- Quilian wrote a program, which defined English words in much the same way like a dictionary:
  - A word is defined in terms of other word, and the components of the definition are defined in the same fashion.
  - Rather than formally defining words in terms of basic axioms, each definition simply leads to other definitions.
  - In looking up a word, we traverse this network until we are satisfied that we understand the original word.

Three planes（平面）representing three definitions of the word “plant”

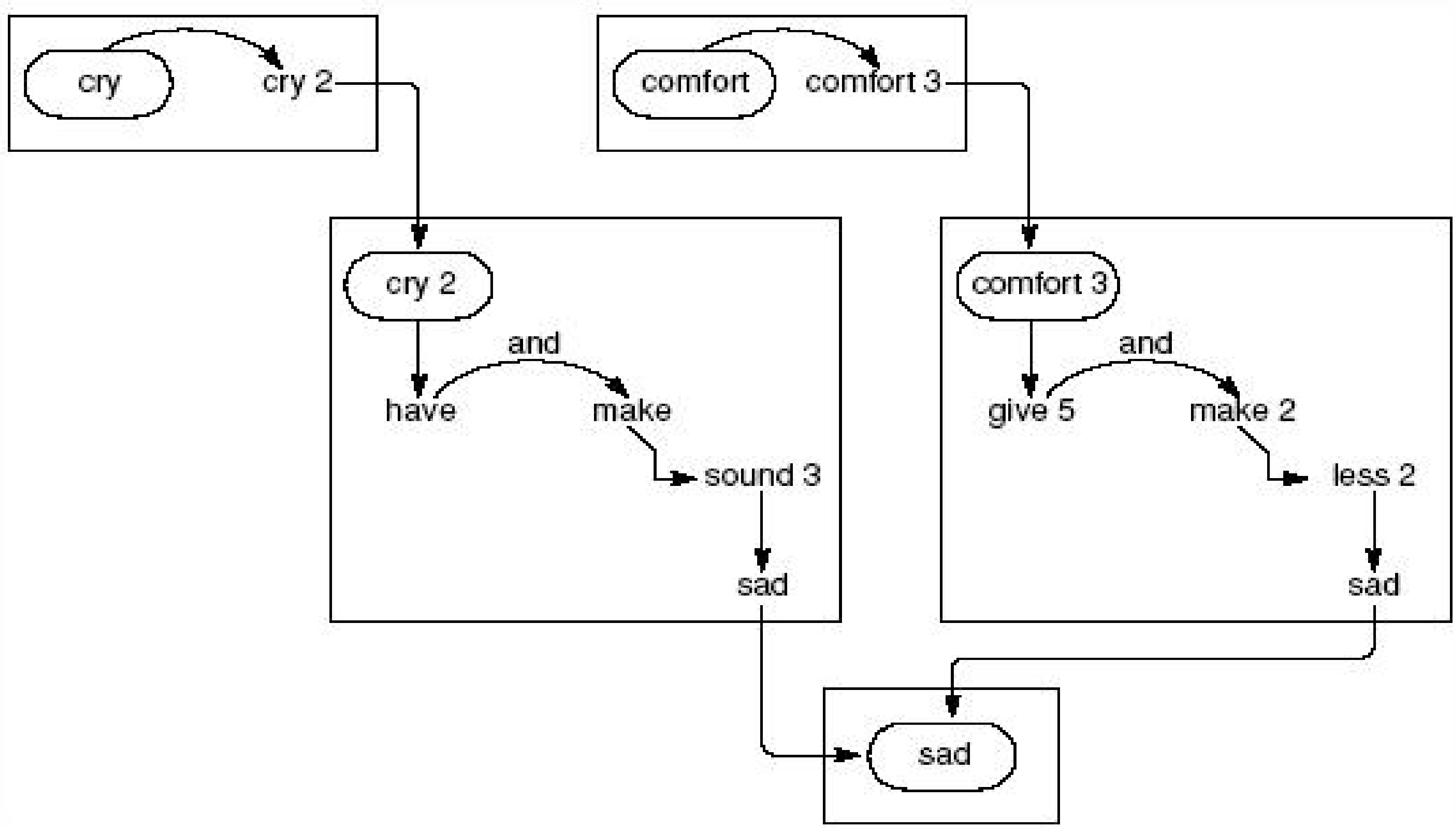
Plant:1) Living structure that is not an animal, frequently with leaves, getting its food from air, water, earth.

2) Apparatus used for any process in industry.

3) Put (seed, plant, etc.) in earth for growth.



Intersection path between “cry” and “comfort”



Cry 2 is among other things to make a sad sound.
To comfort 3 can be to make 2 something less sad

This approach might provide a natural language understanding system with the ability to :

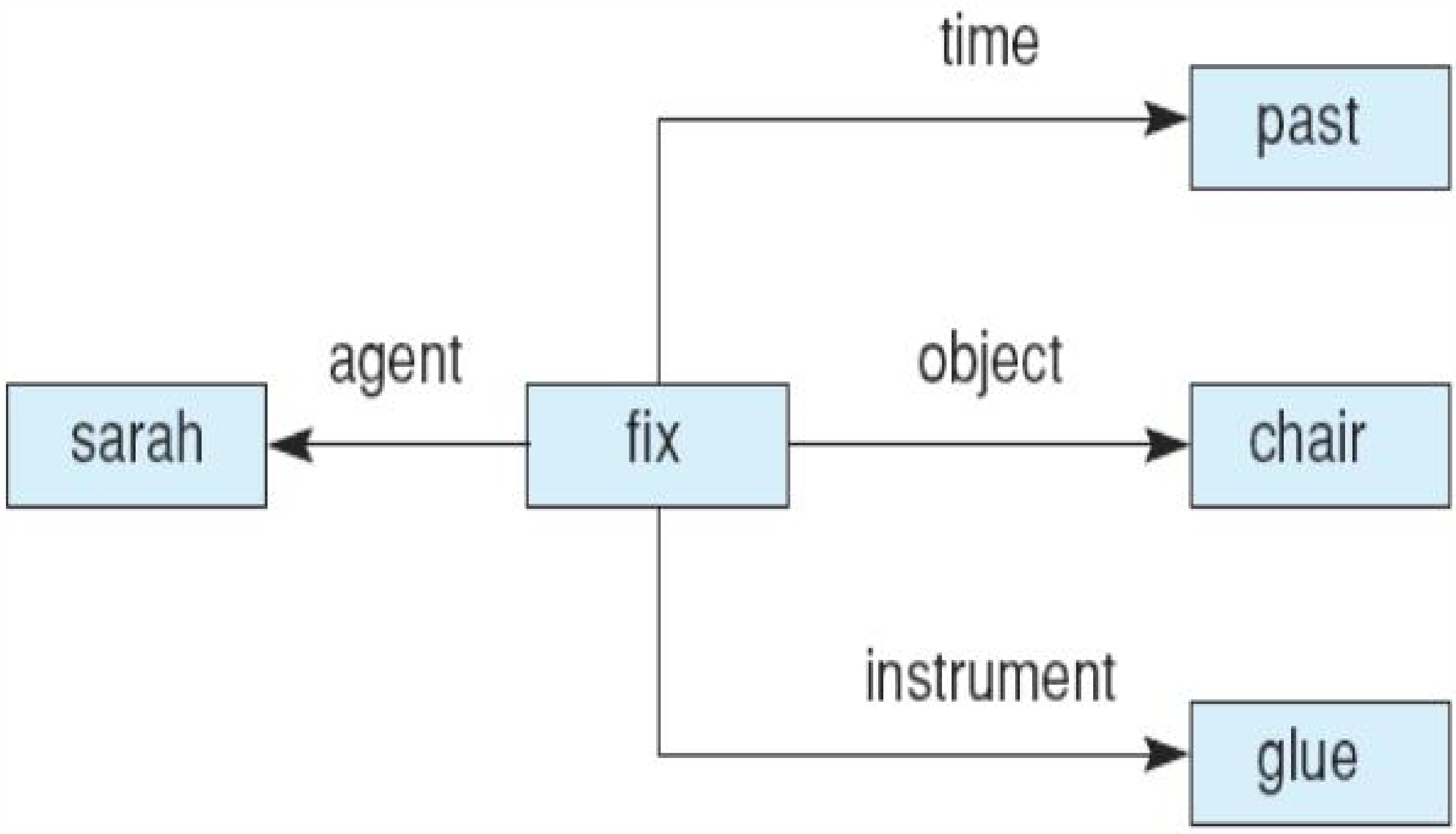
1. Determine the meaning of English text by building up collections of these intersection（相交）nodes.
2. Choose between multiple meanings of words by finding the meanings with the shortest intersection path to other words in the sentence. For example, “Tom went to home to water his new plant.”
3. Answer queries based on associations between word concepts in the queries and concepts in the system.

7.1.3 Standardization of Network Relationships

Simmons(1973) addressed this need for standard relationships by focusing on the *case structure* of English verbs.

- Case relationships（格关系）include agent（主体）, instrument, location, and time.
- A sentence is represented as a verb node, with various case links to nodes representing other participants in the action.
- This structure is called a case frame（格框架）.

Case frame representation of the sentence "Sarah fixed the chair with glue."



Construct case frame representations for the following English sentences, as shown in Figure 7.5.

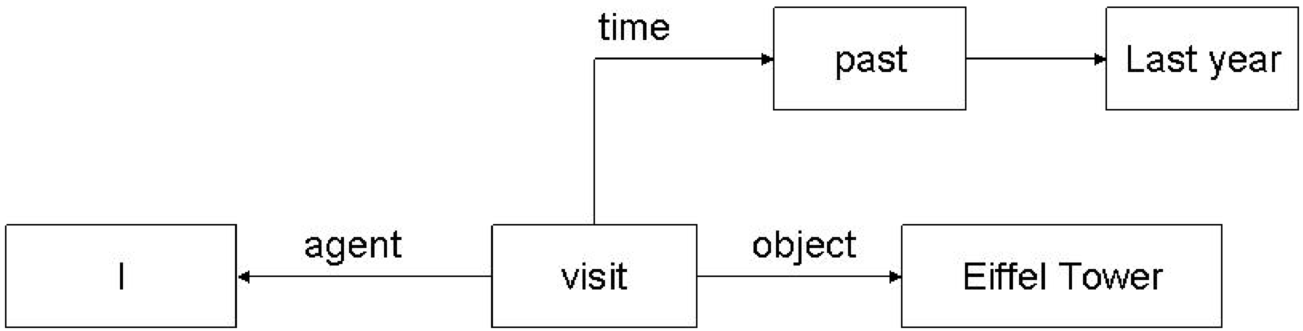
a.) I visited the Eiffel Tower last year.

b.) Mary likes margaritas on the beach.

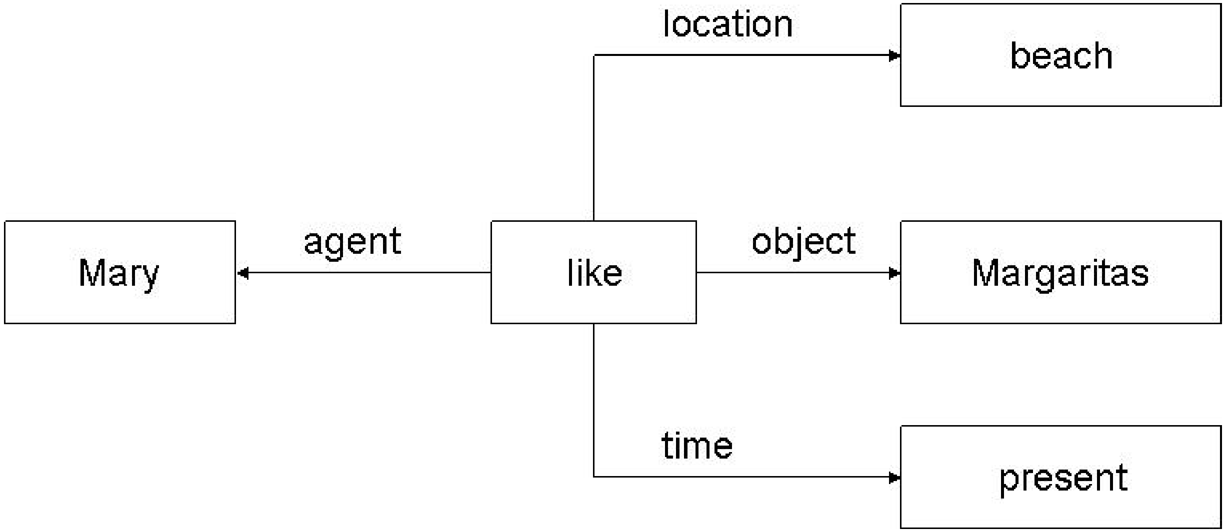
c.) The building was designed by Sergio.

d.) Keisha worked for six years in London.

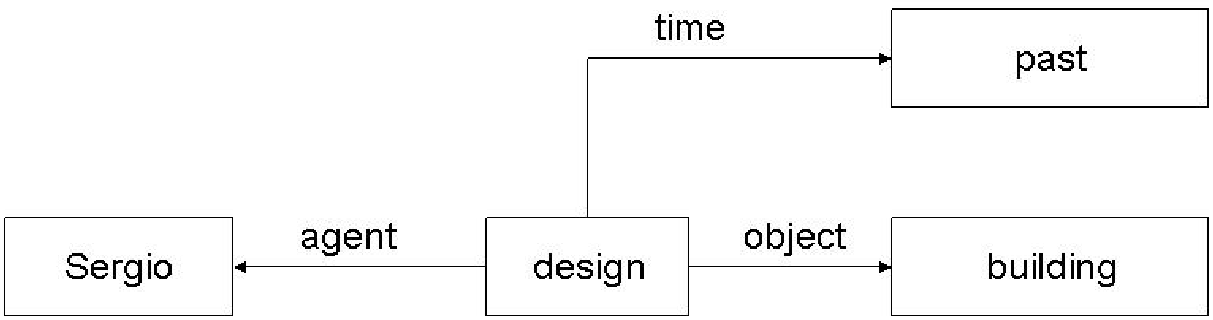
e.) John will take the car to the shop tomorrow.



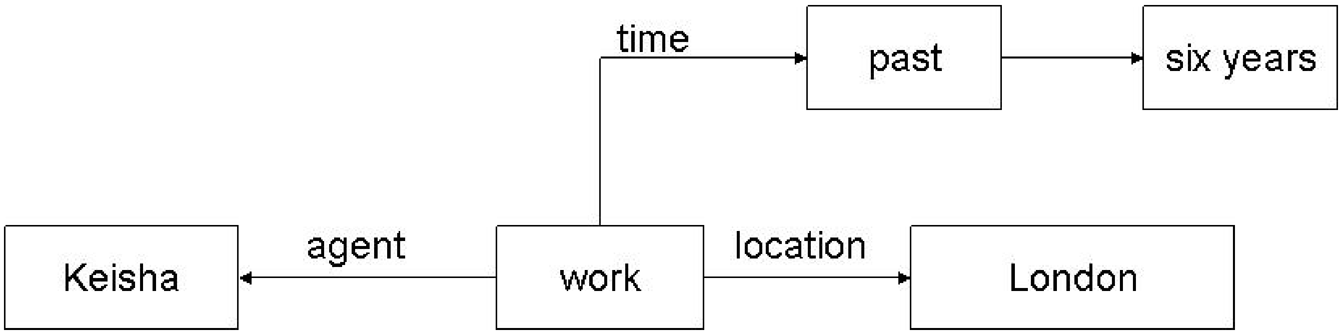
a.) I visited the Eiffel Tower last year.



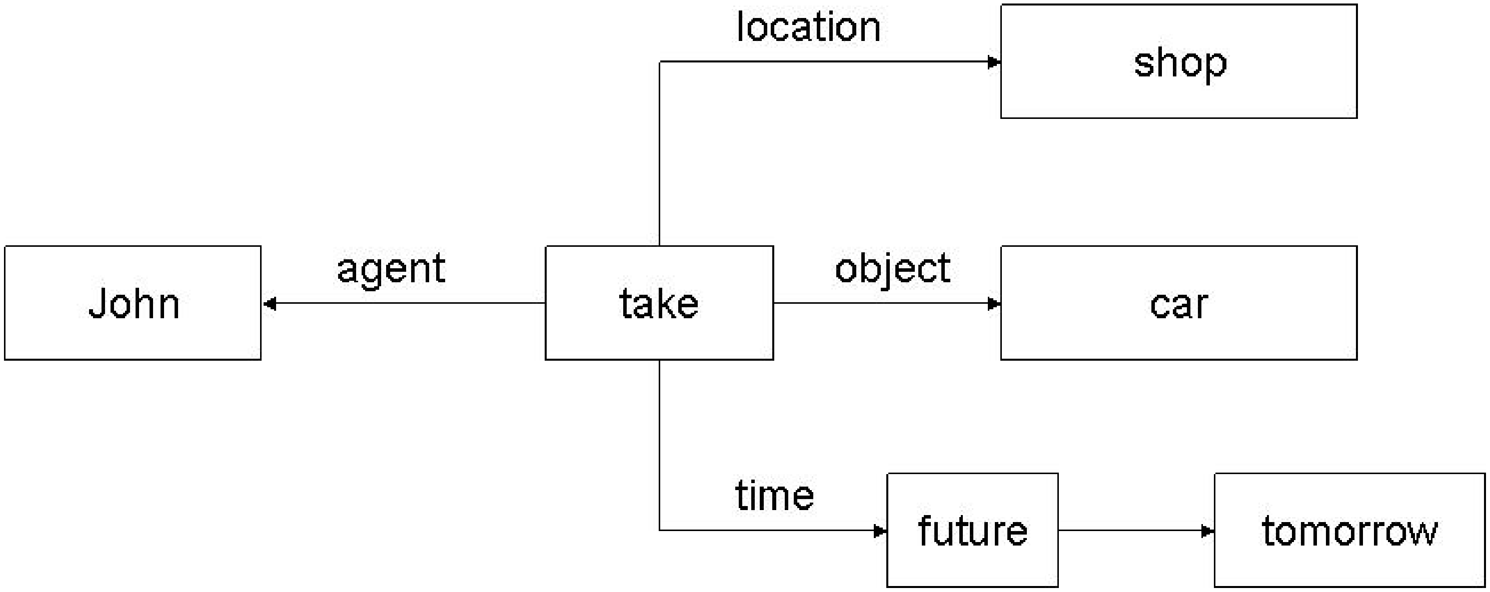
b.) Mary likes margaritas on the beach.



c.) The building was designed by Sergio.



d.) Keisha worked for six years in London.



e.) John will take the car to the shop tomorrow.

conceptual dependency theory
（概念依赖理论）

- This theory offers a set of four primitive conceptualizations（原语概念）from which the world of meaning is built.

  ACTs： actions

  PPs： objects (Picture Producers)

  AAs： modifiers of actions (Action Aiders)

  PAs： modifiers of objects (Picture Aiders)

- Picture：思维形象，化身

- All actions are assumed to reduce to one or more of the primitive ACTs
- The primitives listed below are taken as the basic components（部件） of action.

- ATRANS : transfer a relationship (give)
- PTRANS : transfer physical location of an object (go)
- PROPEL : apply physical force to an object (push)
- MOVE : move body part by owner (kick)
- GRASP : grab an object by an actor (grasp)
- INGEST : ingest（摄取） an object by an animal (eat)

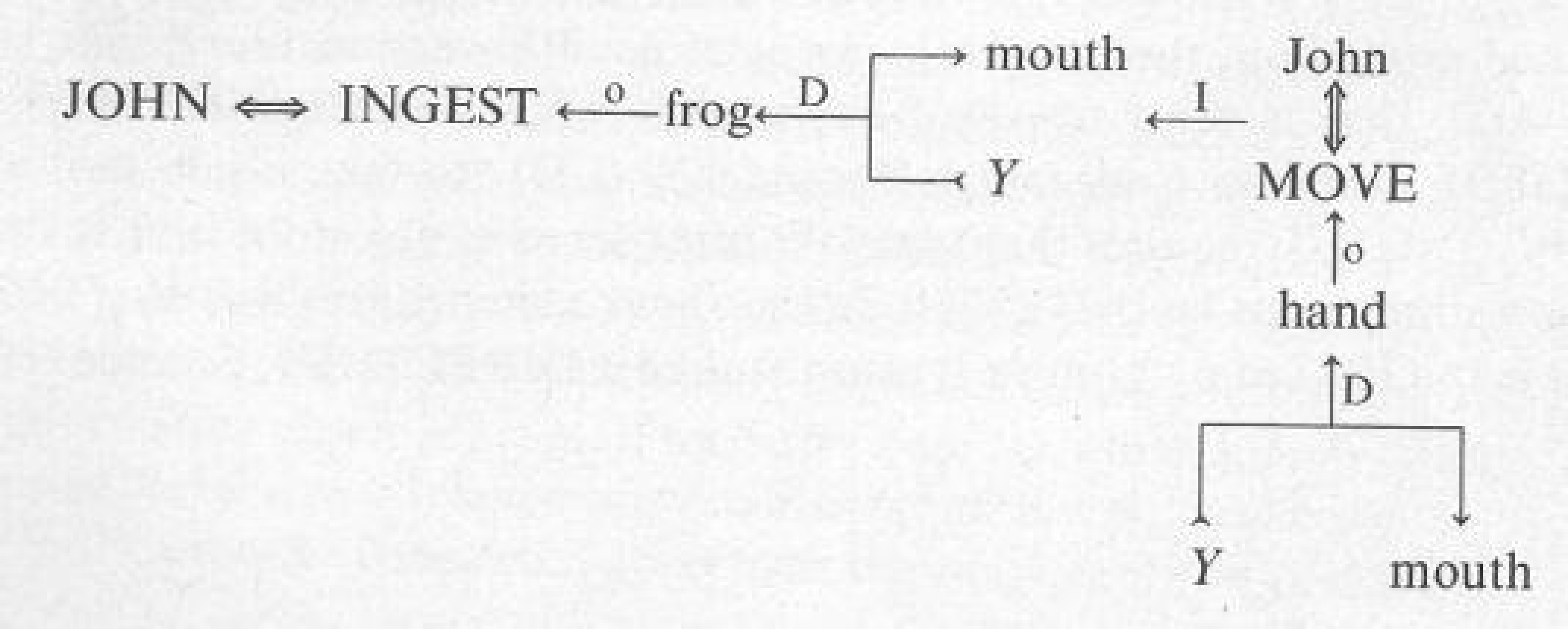
- **EXPEL : expel（排出) from an animal's body (cry)**
- **MTRANS : transfer mental information (tell)**
- **MBUILD : mentally make new information (decide)**
- **CONC : conceptualize（概念化）or think about an idea (think)**
- **SPEAK : produce sound (say)**
- **ATTEND : focus sense organ（感觉器官）(listen)**

Fig 7.6 Conceptual dependencies (relationships)

$PP \Leftrightarrow ACT$	indicates that an actor acts.
$PP \Leftrightarrow PA$	indicates that an object has a certain attribute.
$ACT \overset{O}{\leftarrow} PP$	indicates the object of an action.
$ACT \overset{R}{\leftarrow} \begin{cases} \rightarrow PP \\ \leftarrow PP \end{cases}$	indicates the recipient and the donor of an object within an action. （赠送者）
$ACT \overset{D}{\leftarrow} \begin{cases} \rightarrow PP \\ \leftarrow PP \end{cases}$	indicates the direction of an object within an action.
$ACT \overset{I}{\leftarrow} \Updownarrow$	indicates the instrumental conceptualization for an action.
$\begin{matrix} X \\ \Uparrow \\ Y \end{matrix}$	indicates that conceptualization X caused conceptualization Y. When written with a C this form denotes that X COULD cause Y.
$PP \Leftarrow \begin{cases} \rightarrow PA2 \\ \leftarrow PA1 \end{cases}$	indicates a state change of an object.
$PP1 \leftarrow PP2$	indicates that PP2 is either PART OF or the POSSESSOR OF PP1.

“John throws the ball”.

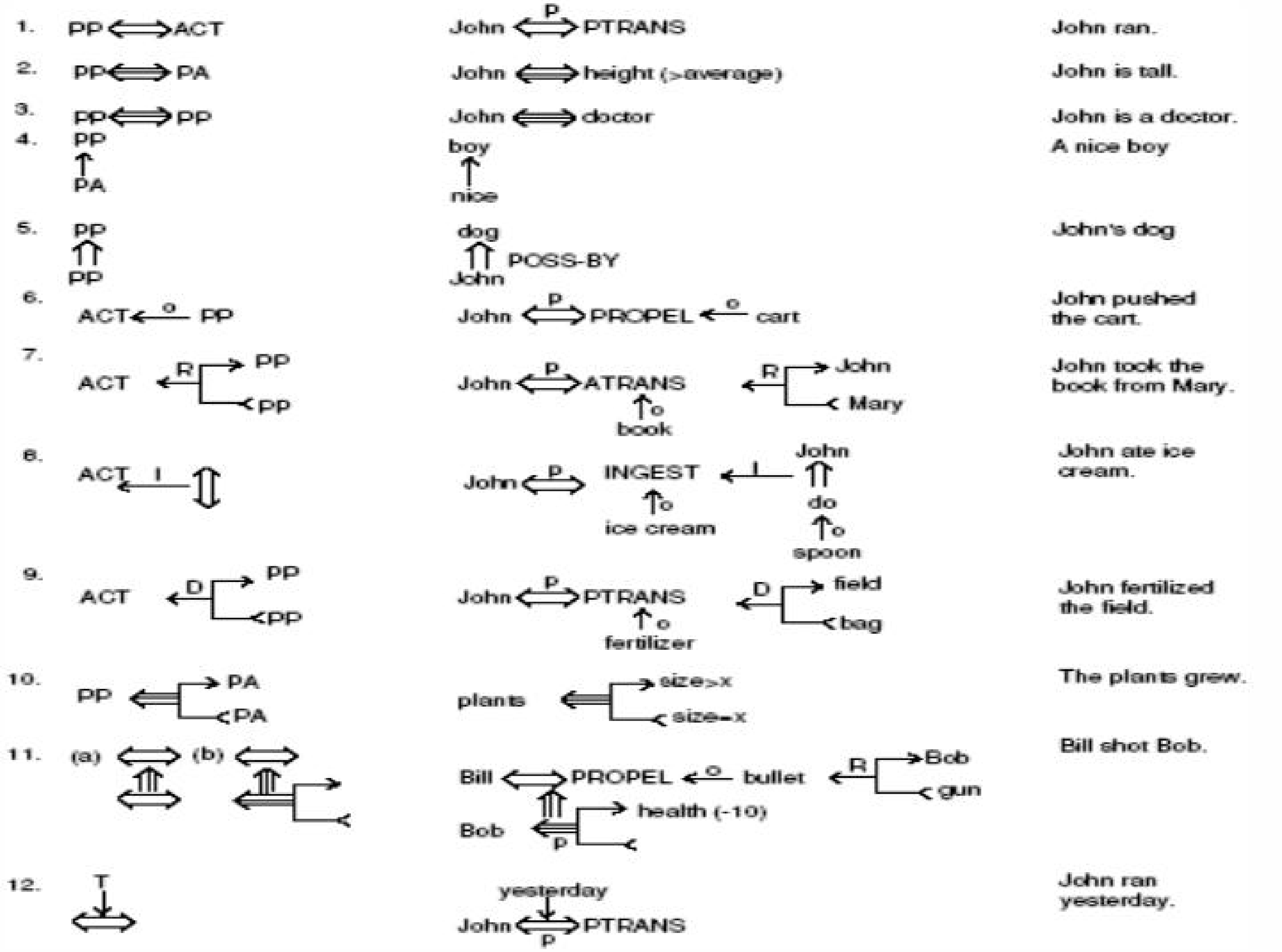
'*John ate a frog*.'



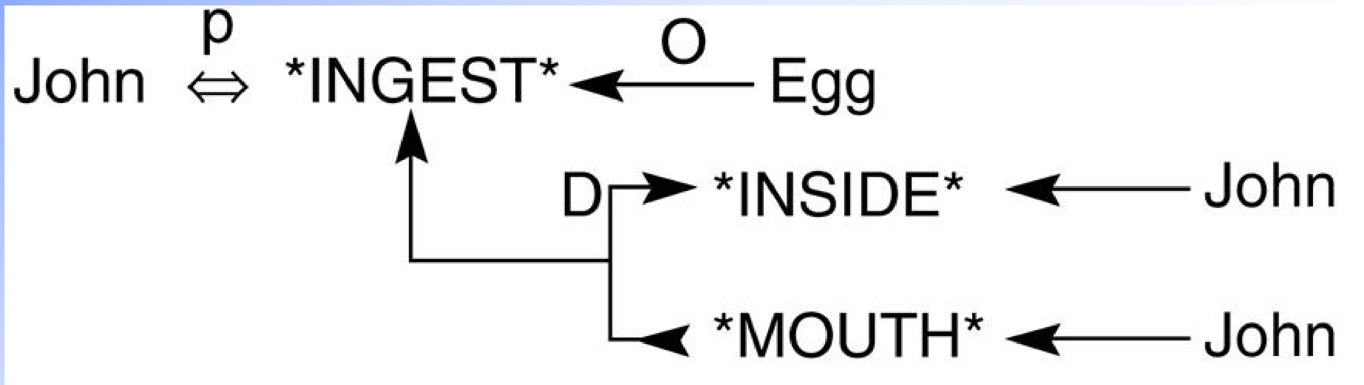
A partial list of tense and mode modifiers

p	past
f	future
t	transition
k	continuing
ts	start transition
?	Interrogative(疑问)
tf	finish transition
c	conditional
/	negative（反义）
nil	present
delta?	timeless（永恒的）

- **The following is some basic conceptual dependencies and their use in representing more complex English sentences.**


1. PP ⟺ ACT
John ⟺ PTRANS (p)
John ran.
2. PP ⟺ PA
John ⟺ height (>average)
John is tall.
3. PP ⟺ PP
John ⟺ doctor
John is a doctor.
4. PP ↑ PA
boy ↑ nice
A nice boy
5. PP ⇑ PP
dog ⇑ POSS-BY John
John's dog
6. ACT ←o PP
John ⟺ PROPEL ←o cart (p)
John pushed the cart.
7. ACT ←R PP PP
John ⟺ ATRANS (p) ←R John Mary
book (o)
John took the book from Mary.
8. ACT ←I ⇕
John ⟺ INGEST (p) ←I John ⇑ do
ice cream (o)
spoon (o)
John ate ice cream.
9. ACT ←D PP PP
John ⟺ PTRANS (p) ←D field bag
fertilizer (o)
John fertilized the field.
10. PP ⇐ PA PA
plants ⇐ size>x size=x
The plants grew.
11. (a) (b)
Bill ⟺ PROPEL ←o bullet ←R Bob gun
Bob ⇐ health (-10) (p)
Bill shot Bob.
12. T
yesterday
John ⟺ PTRANS (p)
John ran yesterday.

“John ate the egg”



← ：Indicates the direction of dependency

⇔ ：Indicates the agent-verb relationship

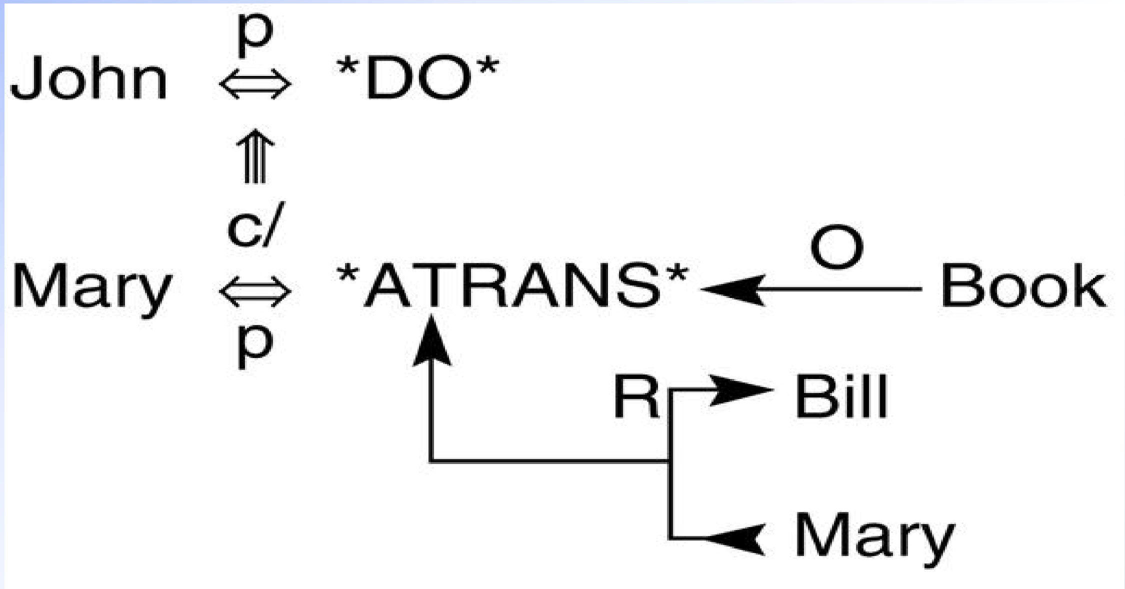
P ：Indicates past tense

O ：Object relation

D ：Indicates the direction of the object in the action

INGEST ：is a primitive act of the theory

“John prevented Mary from giving a book to Bill”



R： Indicates the recipient and donor （赠送者） of an object in the action

c: conditional

/: negative

Conceptual dependency theory provides a formal theory of natural semantics

- Important benefits of conceptual dependency theory :

1. It reduces the problem of ambiguity（歧义，多义性）.
2. It directly captures much of natural language semantics, by attempting to provide a canonical form（范式）for the meaning of sentences.

- **Deficiencies of conceptual dependency theory :**
- **Possibility : reduce all sentences to such low-level canonical form（范式）.**
- **The primitives are not adequate for subtle（微妙） concepts, such as “tall”**

7.1.4 Scripts

- A script（脚本）is a structured representation describing a stereotyped（固定的）sequence of events in a particular context.
- Entry conditions(进入条件)： descriptors of the world that must be true for the script to be called.
- Results （结果）： facts that are true once the script has terminated
- Props（道具）： the things that support the content of the scripts
- Roles（角色）are the actions that the individual participants perform.
- Scene（场景）： the scripts are broke into a sequence of scenes, each of which presents a temporal aspect of the script.

Fig 7.11

a restaurant script

Script: RESTAURANT
Track: Coffee Shop
Props: Tables
Menu
F = Food
Check
Money

Roles: S = Customer
W = Waiter
C = Cook
M = Cashier
O = Owner

Entry conditions: S is hungry.
S has money.

Results: S has less money
O has more money
S is not hungry
S is pleased (optional)

Scene 1: Entering

S PTRANS S into restaurant
S ATTEND eyes to tables
S MBUILD where to sit
S PTRANS S to table
S MOVE S to sitting position

Scene 2: Ordering

(Menu on table) (W brings menu)
S PTRANS menu to S

(S asks for menu)
S MTRANS signal to W
W PTRANS W to table
S MTRANS 'need menu' to W
W PTRANS W to menu

W PTRANS W to table
W ATRANS menu to S

S MTRANS food list to CP (S)
*S MBUILD choice of F
S MTRANS signal to W
W PTRANS W to table
S MTRANS 'I want F' to W

W PTRANS W to C
W MTRANS (ATRANS F) to C

C MTRANS 'no F' to W
W PTRANS W to S
W MTRANS 'no F' to S
(go back to *) or
(go to Scene 4 at no pay path)

C DO (prepare F script)
to Scene 3

Scene 3: Eating

C ATRANS F to W
W ATRANS F to S
S INGEST F

(Option: Return to Scene 2 to order more;
otherwise, go to Scene 4)

Scene 4: Exiting

S MTRANS to W
(W ATRANS check to S)

W MOVE (write check)
W PTRANS W to S
W ATRANS check to S
S ATRANS tip to W
S PTRANS S to M
S ATRANS money to M
S PTRANS S to out of restaurant

(No pay path)

- **Example 7.1.1**

  John went to a restaurant last night. He ordered steak. When he paid he noticed that he was running out of money. He hurried home since it had started to rain.

  - **Did John eat dinner last night ?**

- **Example 7.1.2**

  Amy Sue went out to lunch. She sat at a table and called a waitress, who brought her a menu. She ordered a sandwich.

  - **Why did the waitress bring Amy Sue a menu ?**

- **Example 7.1.3**

  Kate went to a restaurant. She has shown to a table and ordered sushi from the waitress. She sat there and waited for a long time. Finally, she got mad and left.

  - **Who is the “she” who sat and waited ?**

- **Example 7.1.4**

  John visited his favorite restaurant on the way to the concert. He was pleased by the bill because he liked Mozart.

  - **Potential script selection : “key” words matching, fallible**

- **Example 7.1.5**

Melissa was eating dinner at her favorite restaurant when a large piece of plaster（石膏） fell from the ceiling and landed on her date（椰枣）.

Questions:

Was Melissa eating a date salad?

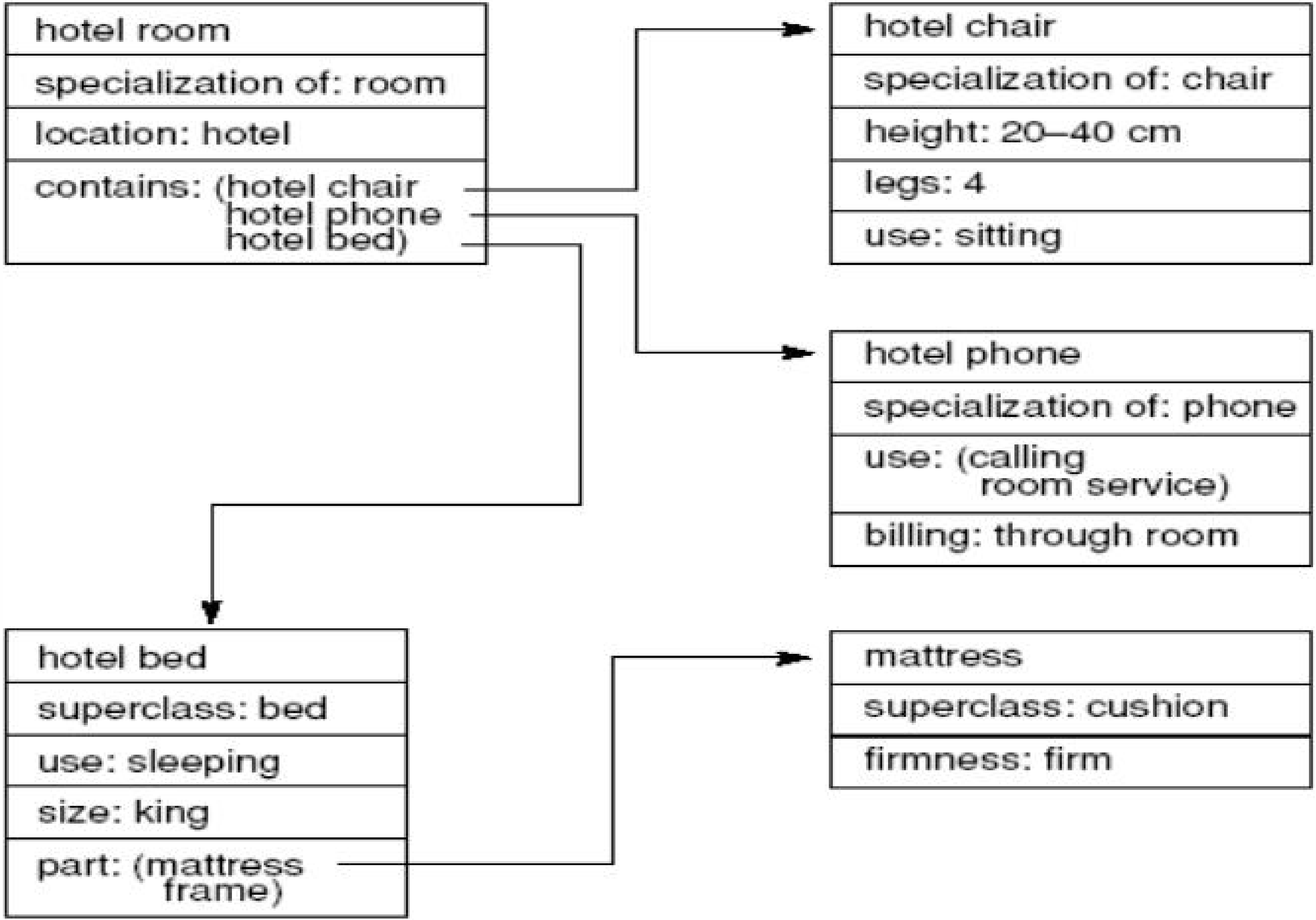
Was Melissa's date plastered?

What did she do next?

7.1.5 Frames——Minsky 1975

- When one encounters a new situation one selects from memory a structure called frame （框架）.
- This is a remembered framework to be adapted to fit reality（现实）by changing details as necessary.

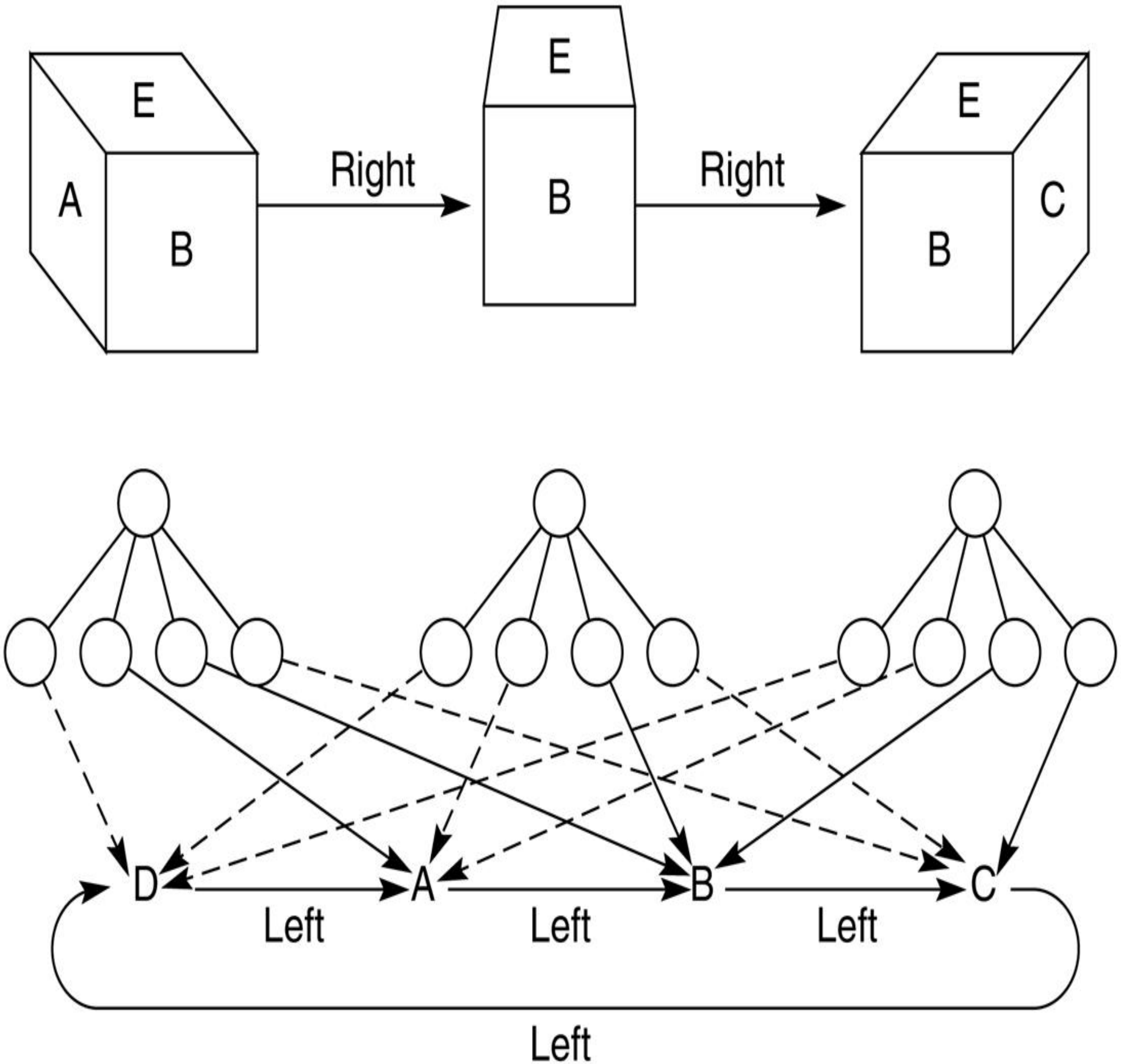
Fig 7.12 Part of a frame description of a hotel room. "Specialization" indicates a pointer to a superclass.



- Frame slots may contain information such as :

1. Frame identification（标识）.
2. Relationship of this frame to other frames.
3. Descriptors（描述符）of requirements for a frame.
4. Procedural information on use of the structure described.
5. Frame default（默认） information.
6. New instance information.

Fig 7.13 Spatial（立体）frame for viewing a cube



Spatial frame

Pictorial frames

Relation markers in common-terminal structure can represent more invariant (e.g., three-dimensional) properties

7.2 Conceptual Graphs: a Network Language

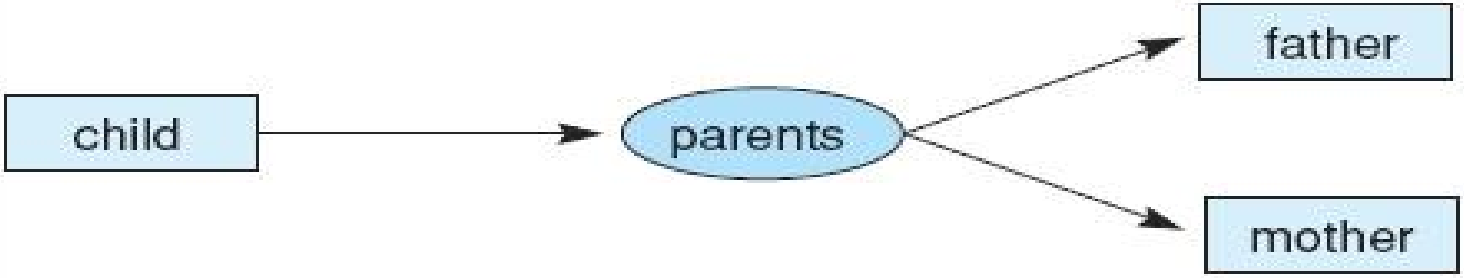
7.2.1 Introduction to Conceptual Graphs

- A conceptual graph（概念图）is a finite, connected, bipartite graph（二部图）.
- The nodes of the graph are either concepts or conceptual relations .
- To distinguish these type of nodes, we represent concepts as boxes and conceptual relations as ellipses(椭圆).

Conceptual relations of different arities.

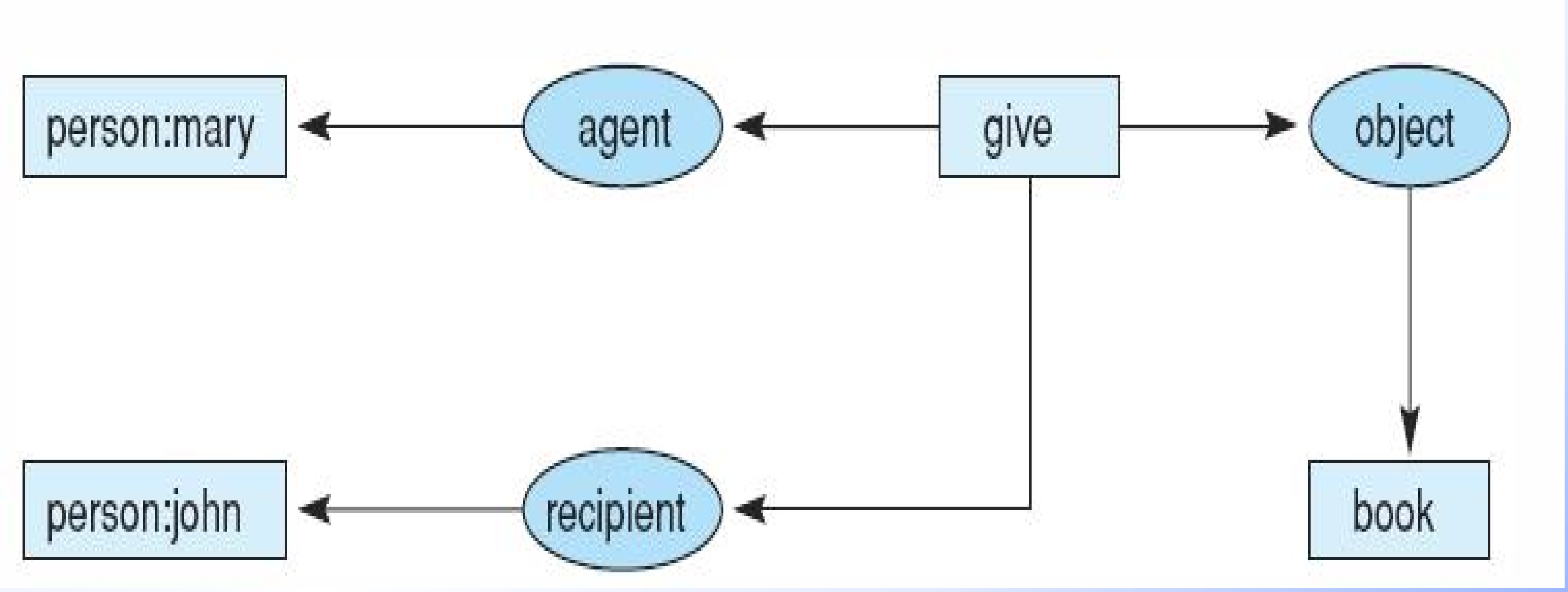
Flies is a 1-ary relation.

Color is a 2-ary relation.



Parents is a 3-ary relation.

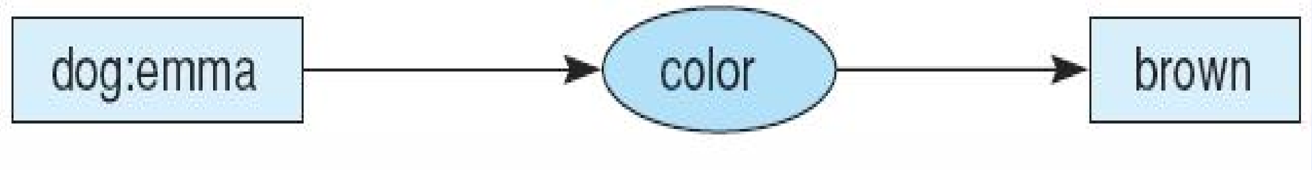
Graph of "Mary gave John the book."



7.2.2 Types, Individuals, and names

- In conceptual graphs, every **concept** is a unique **individual** of a particular **type**.
- Each **concept box** is labeled with a **type label**, which indicates the **class or type** of individual represented by that node.

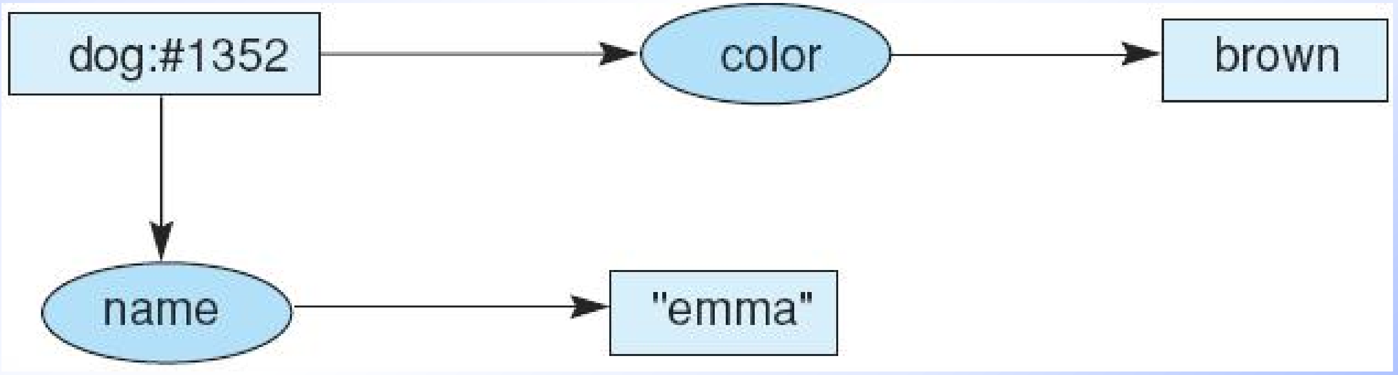
Conceptual graph indicating thatthe dog named Emma is brown.



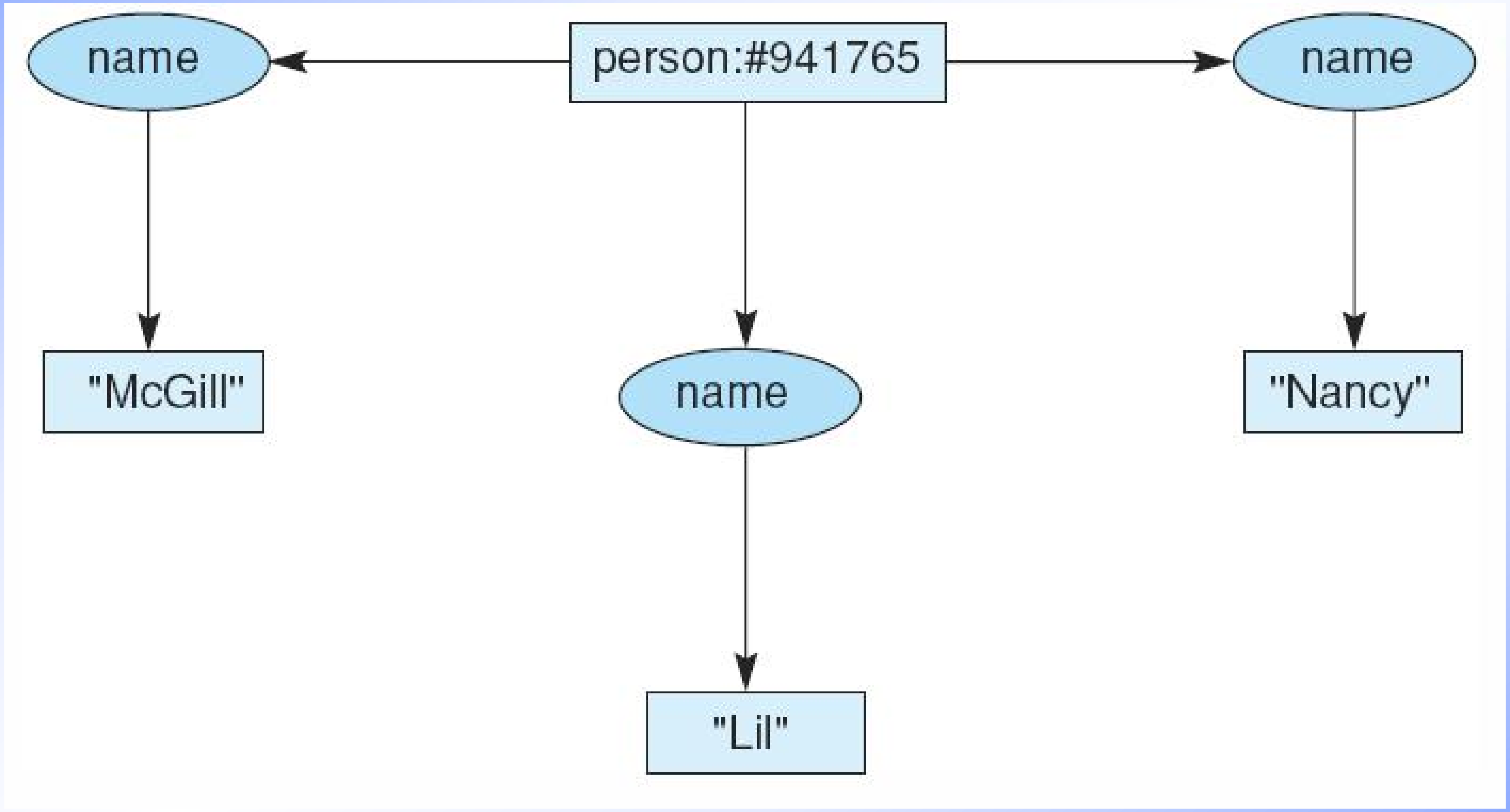
- We can indicate specific but unnamed individuals （无名个体）with markers （标记）.
- A marker is a unique token indicating each individual in the world of discourse.
- This marker is written as a number preceded by a #

A particular (but unnamed) dog is brown.

Conceptual graph indicating that a dog named Emma is brown.



A person with three names

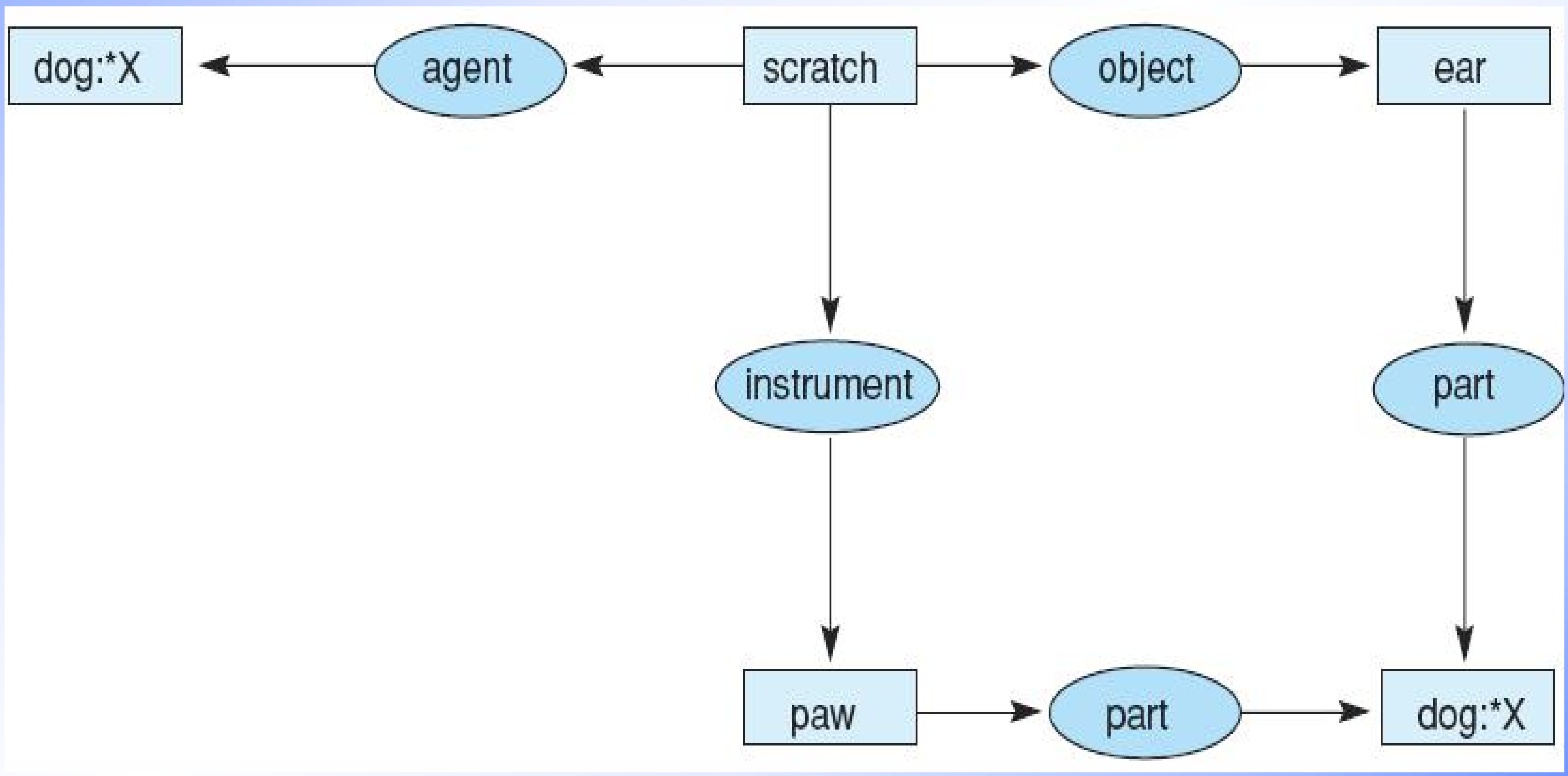


- As an alternative to indicating an individual by its maker or name, we can also use the generic marker * to indicate an unspecified individual.
- By convention(约定),the marker * is often omitted from concept labels; a node labeled dog is equivalent to a node labeled dog:*
- In addition to the generic marker, conceptual graphs allow the use of named variables, such as dog:*x

To summarize, each concept node can indicate an individual of a specified type. This individual is the referent(指向，所指域) of the concept. This reference is indicated either individually or generically. If the referent uses an individual marker, the concept is an individual concept; if the referent uses the generically marker, the concept is generic concept.

Conceptual graph of the sentence

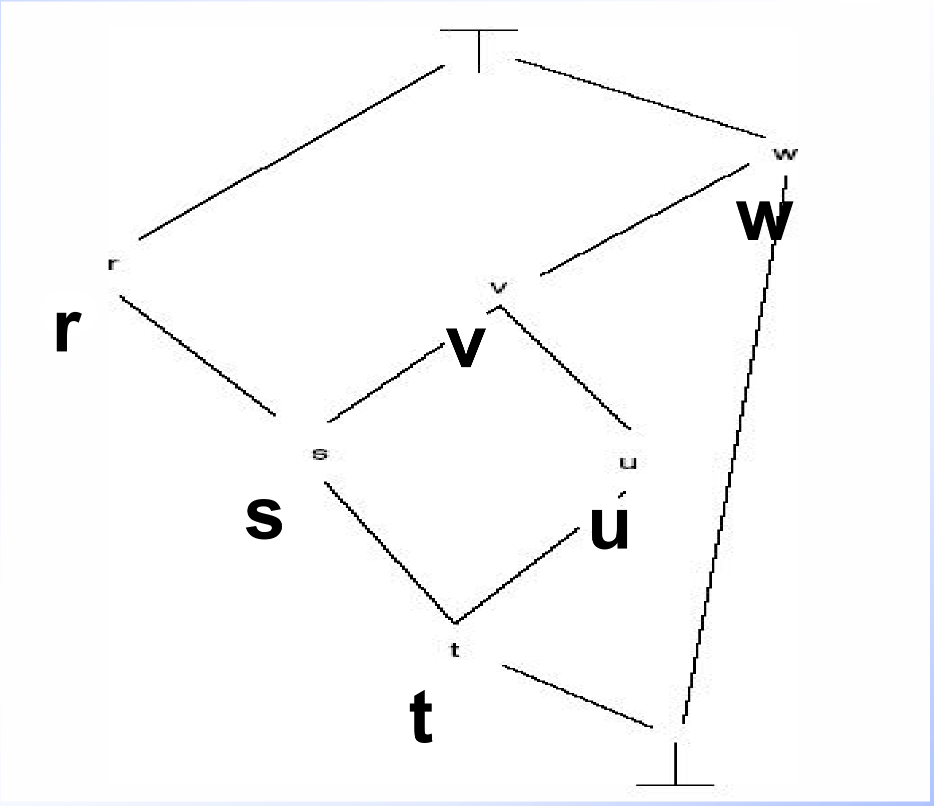
“The dog scratches its ear with its paw.”



7.2.3 The Type Hierarchy

- If s and t are types and t $\leq$ s, then t is said to be a **subtype** of s and s is said to be a **supertype** of t.
- If s, t, and u are types, with t $\leq$s and t $\leq$ u, then t is said to be a **common subtype** of s and u.
- Similarly, if s $\leq$ v and u $\leq$ v then v is a **common supertype** of s and u.
- The **universal（通用） type** is a supertype of all types，indicated by $\top$.
- The **absurd（荒谬） type** is a subtype of all types, indicated by $\perp$.

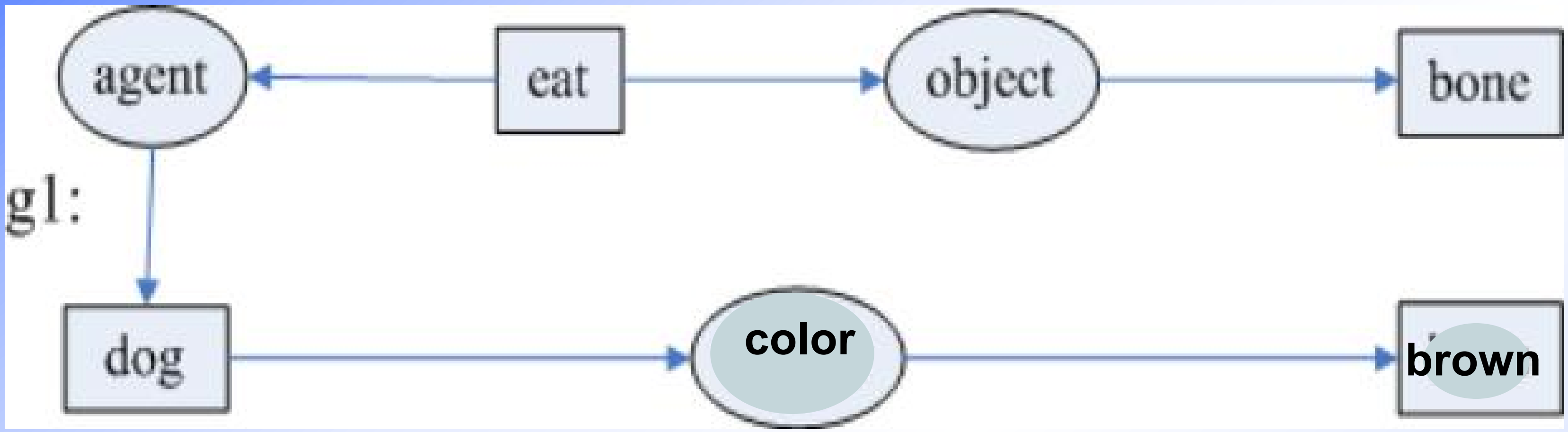
A type lattice（网格）illustrating subtypes, supertypes, the universal type, and the absurd type.

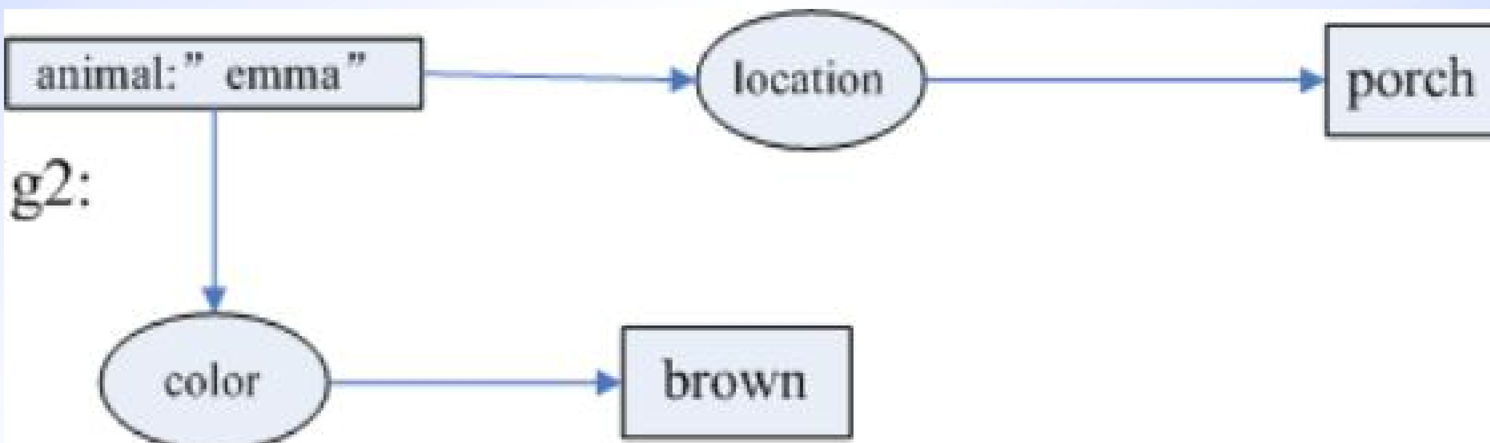


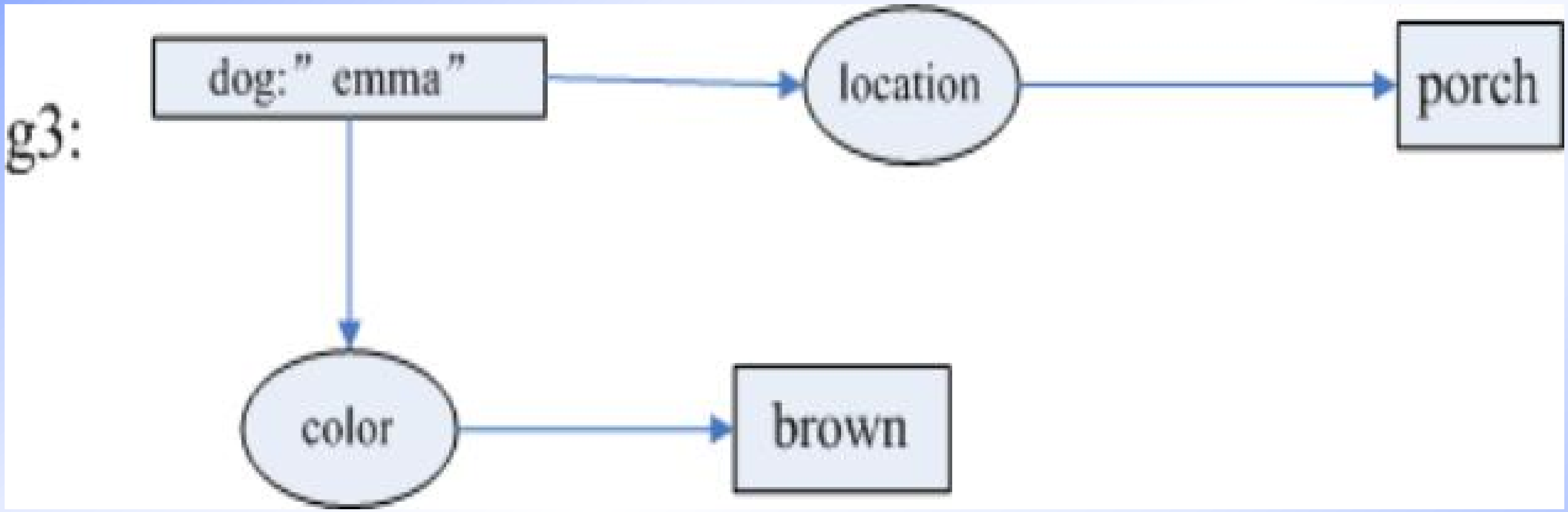
7.2.4 Generalization(泛化) and specialization（特化）

- The copy rule allows us to form a new graph g’ that is the exact copy of graph g
- The join rule lets us combine two graphs into a single graph.
- The simplify rule：If a graph contains two duplicate（重复） relations, then one of them may be deleted.

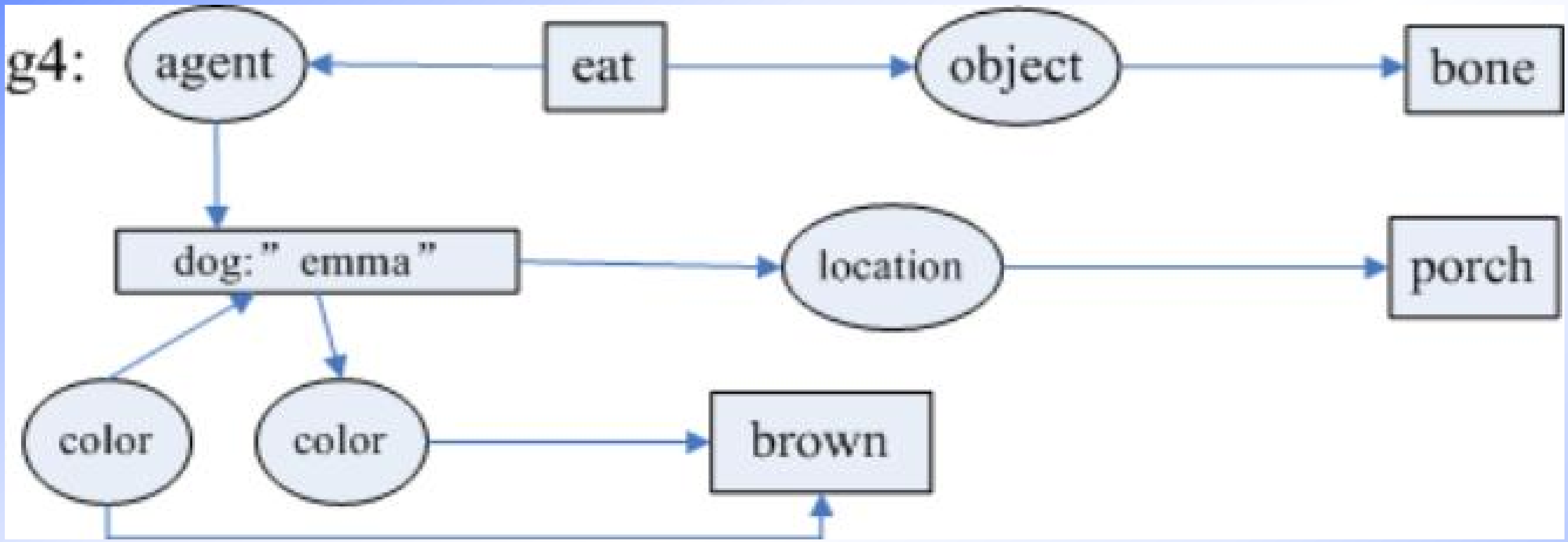
- Restrict rule allows concept nodes to be replaced by a node representing their specialization（特例）. There are two cases:
  - If a concept is labeled with a generic marker, the generic marker may be replaced by an individual marker.
  - A type label may be replaced by one of its subtypes, if this is consistent with the referent（指示对象）of the concept.


g1:
agent
eat
object
bone
dog
color
brown

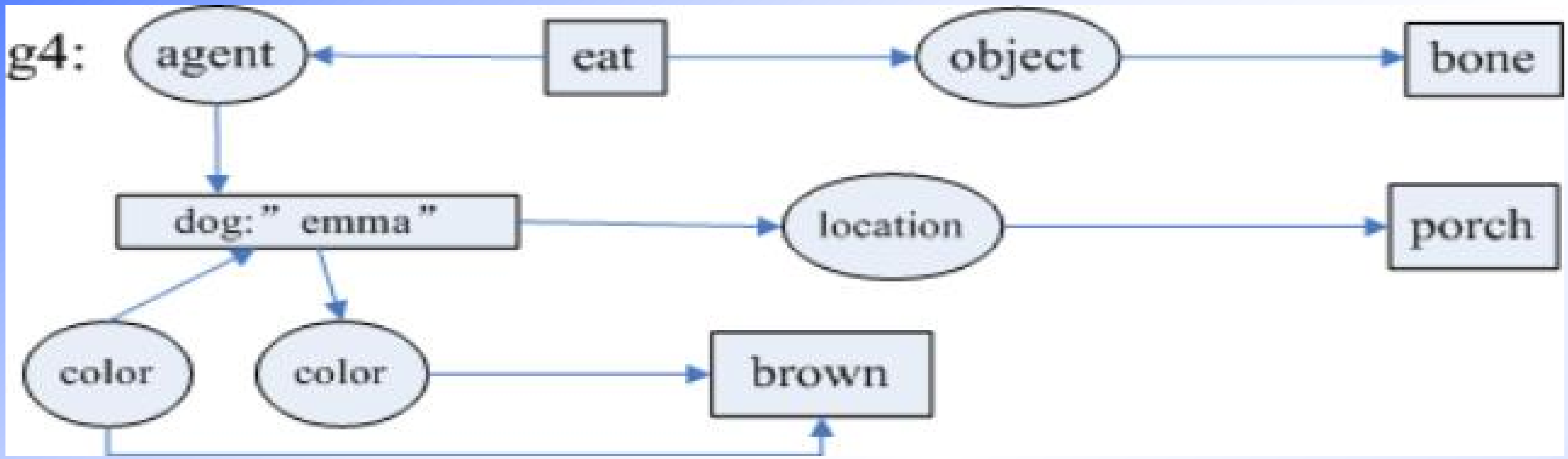

g2:
animal:" emma"
location
porch
color
brown

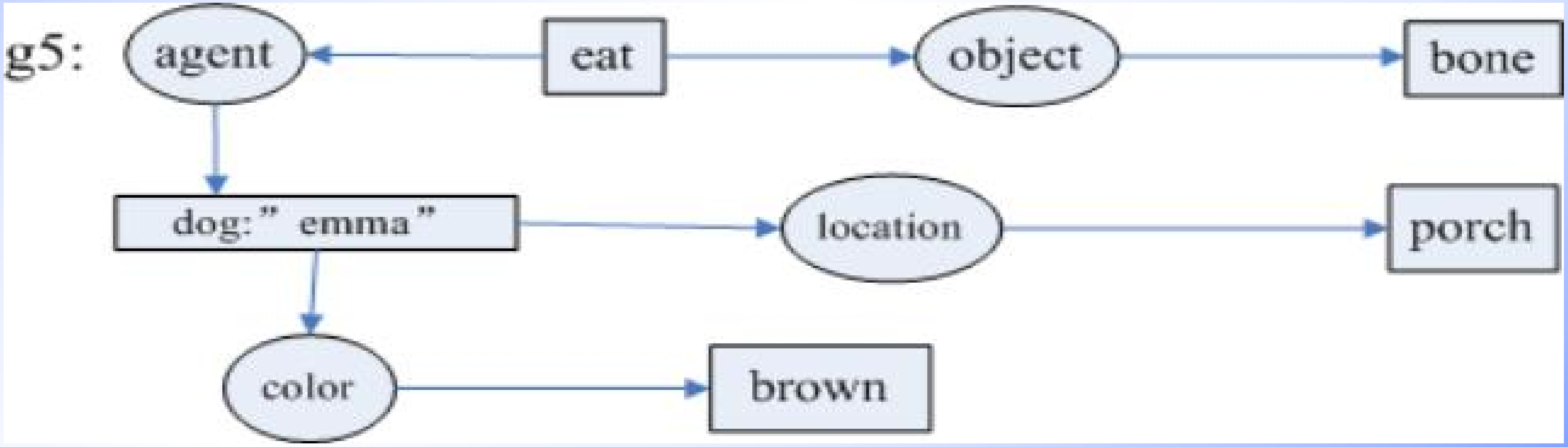


The restriction of g2:



The join of g1 and g3:

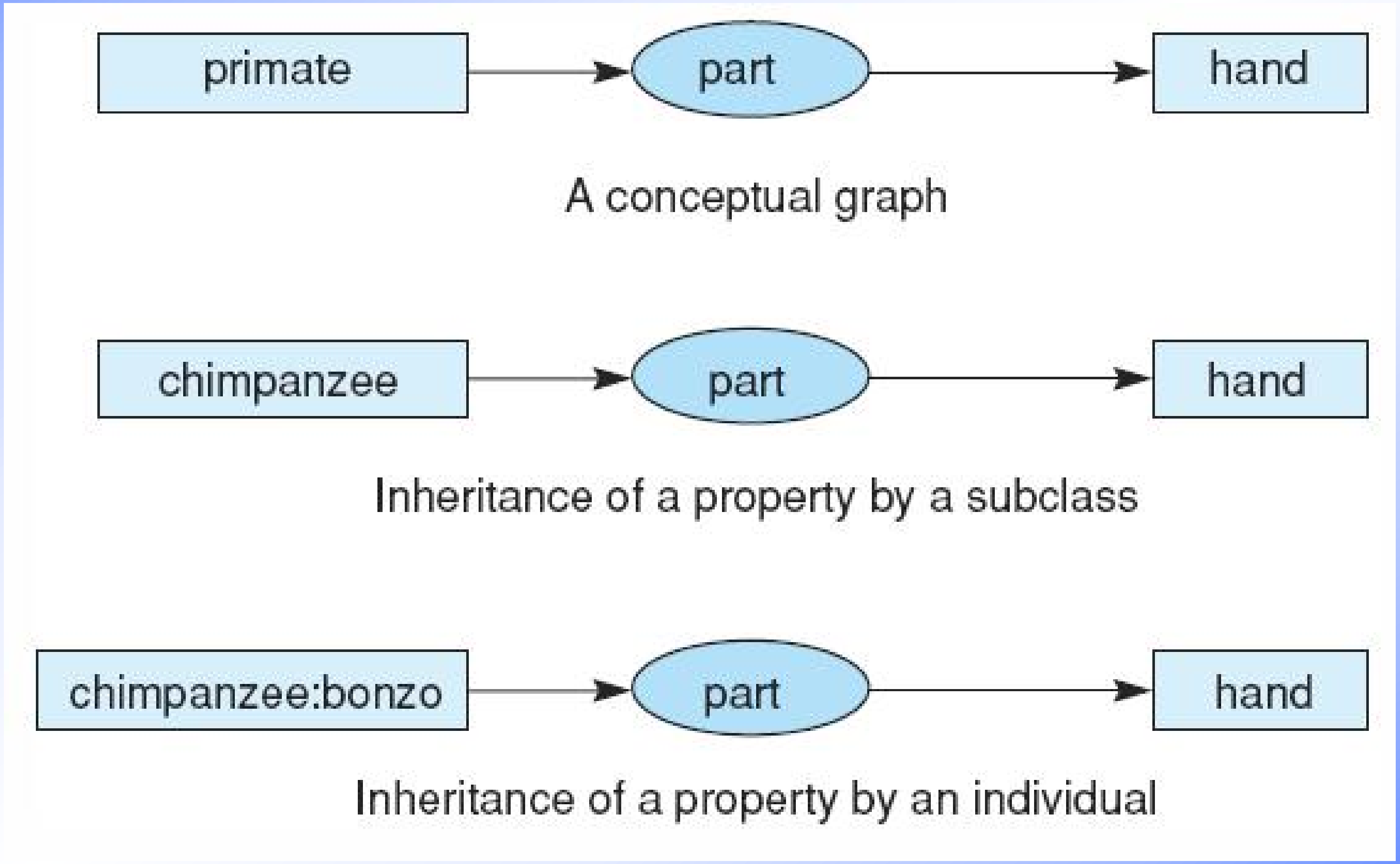




The simplify of g4:

- One use of the restrict rule is to make two concepts match so that a join can be performed.
- Together, restrict and join allow the implementation of inheritance(继承).

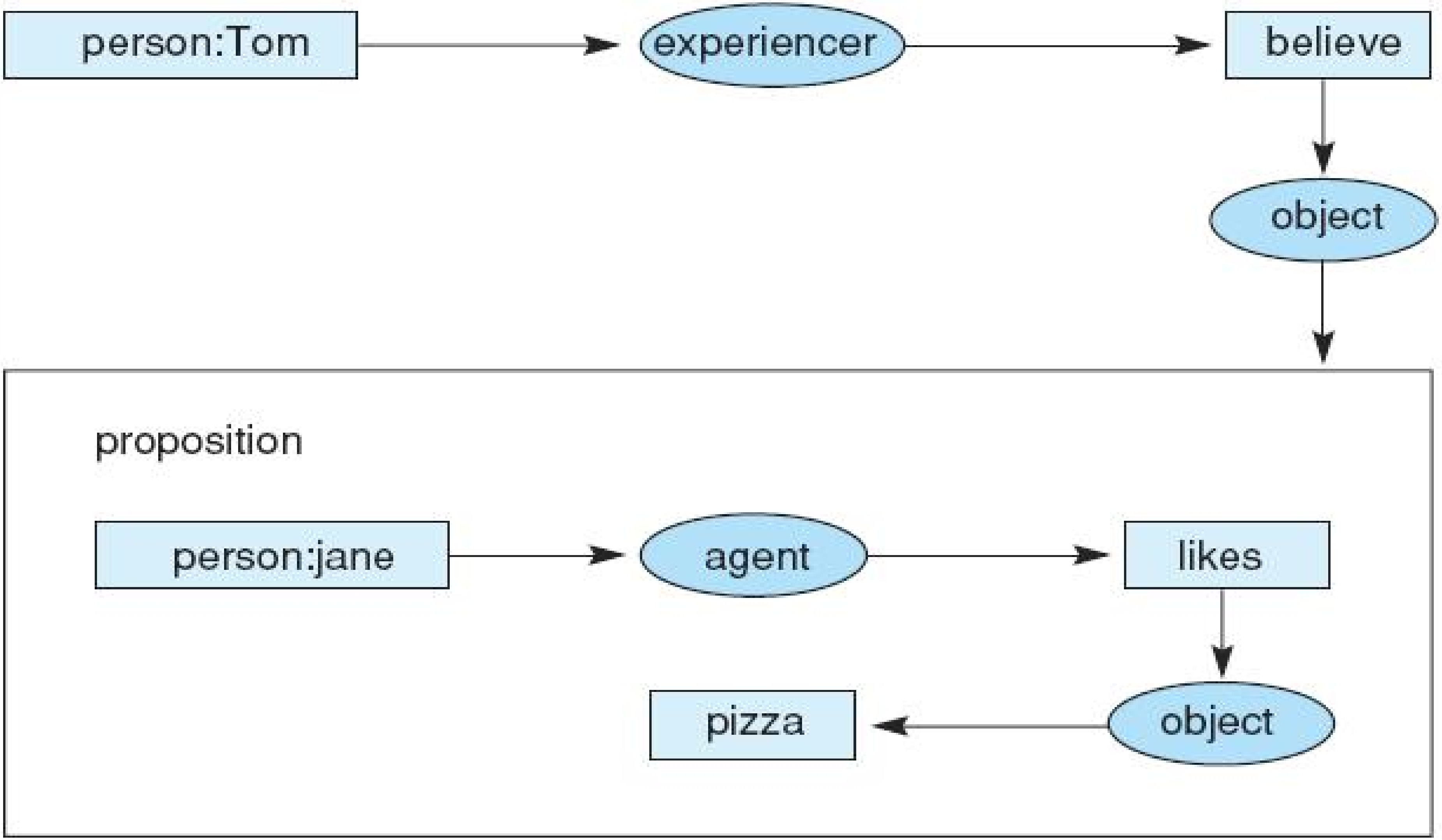
Inheritance in conceptual graphs



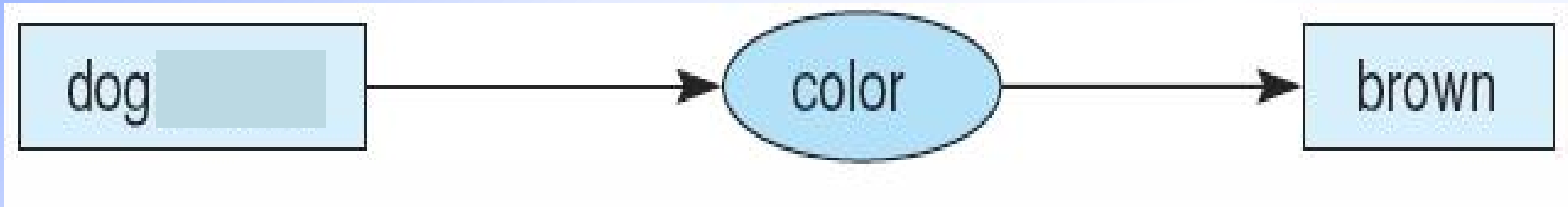
7.2.5 Propositional Nodes

- Conceptual graphs include a special concept type, "proposition"（命题）, that takes a set of conceptual graphs as its referent and allows us to define relations involving propositions.

Conceptual graph of the statement "Tom believes that Jane likes pizza" showing the use of a propositional concept.



7.2.6 Conceptual graphs and Logic

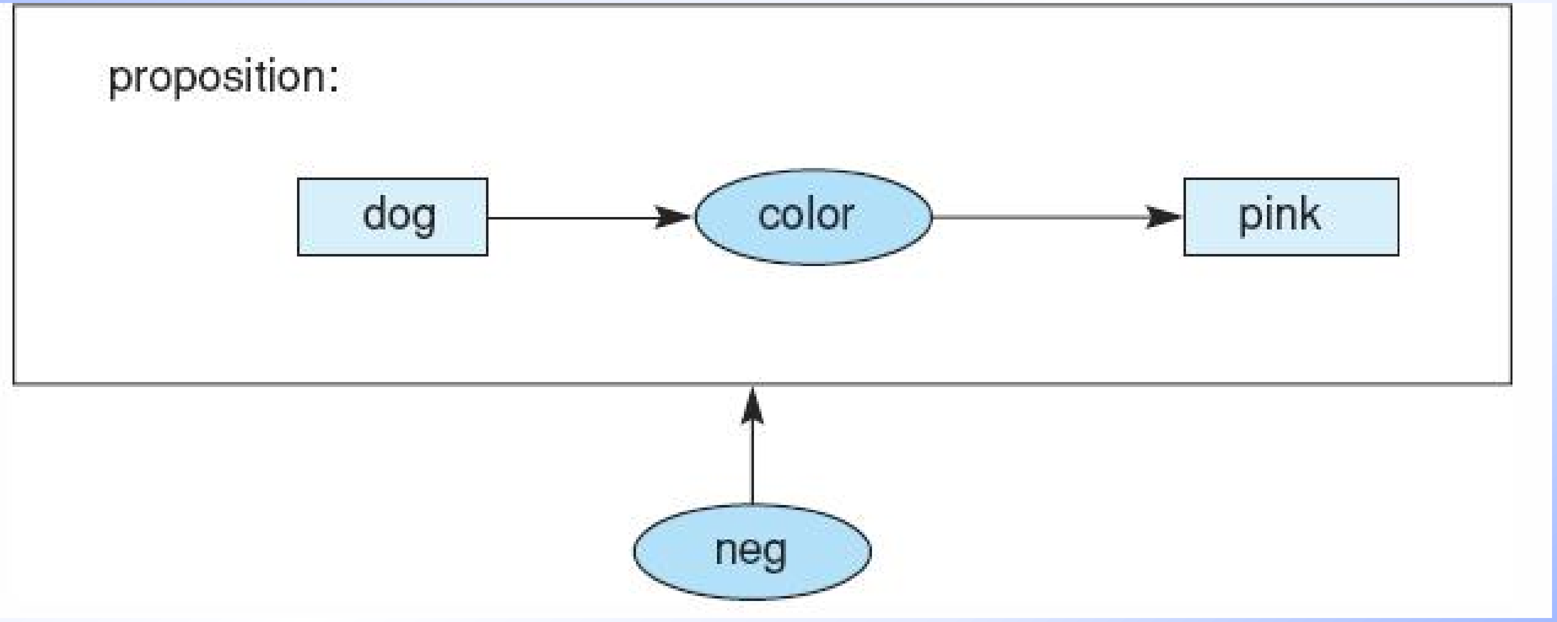


This conceptual graph

corresponds to the logical expression :

$$\exists X \exists Y\ (\ dog(x)\ \wedge color(X,Y)\ \wedge brown(Y)\ )$$

- We may implement negation using propositional concepts and a unary operation（一元运算）called neg.

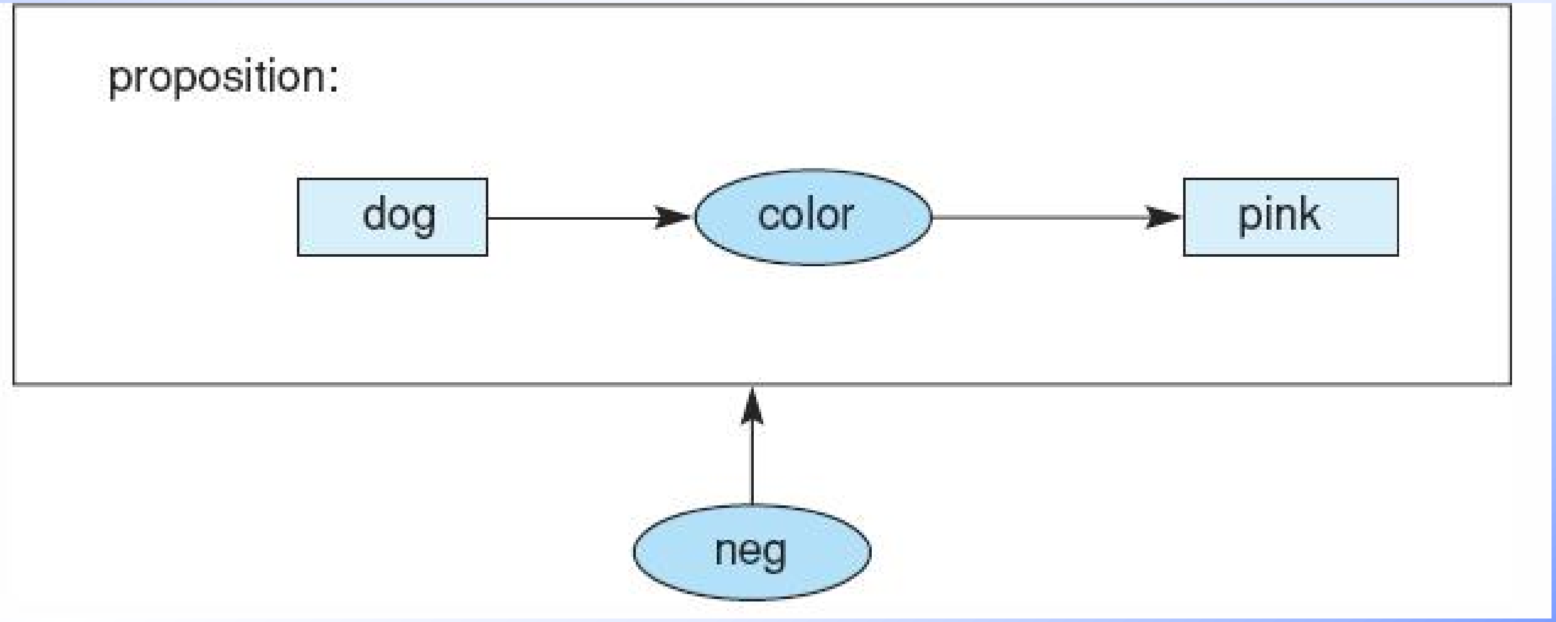


Conceptual graph of the proposition
"There are no pink dogs."

$$\neg \exists X \exists Y \,(\, dog(x) \wedge color(X,Y) \wedge pink(Y)\,)$$

or

$$\forall X\ \forall Y\ \neg (\, dog(X) \wedge color(X,Y) \wedge pink(Y)\,)$$



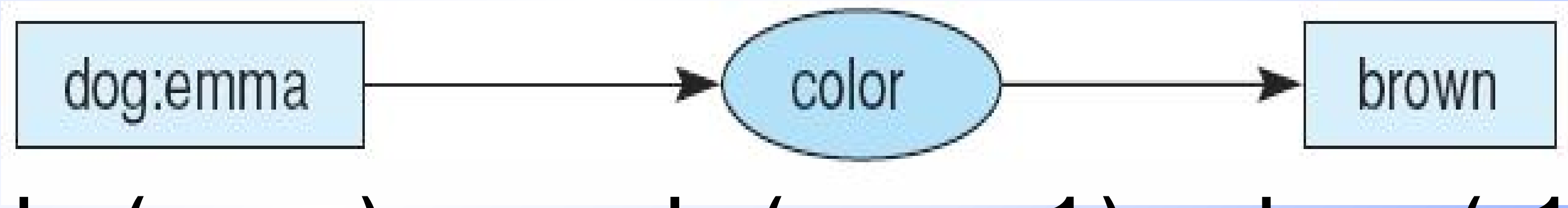
- conceptual graphs are equivalent to predicate calculus in their expressive power.
- There is a straightforward（直接的） mapping from conceptual graphs into predicate calculus expressions.

1. Assign a unique variable, x_1, x_2 …., x_n, to each of the n generic concepts（一般概念）in g.
2. Assign a unique constant to each individual concept（个体概念）in g.
3. Represent each concept node by a unary（一元）predicate with the same name as the type of that node and whose argument is the variable or constant given that node.
4. Represent each n-ary conceptual relation node in g as an n_ary（n 元）predicate whose name is the same as the relation. Let each argument of the predicate be the variable or constant given to the concept nodes linked to that relation.
5. Take the conjunction of all atomic sentences formed under 3 and 4.

Example :

$$\exists x1(dog(emma) \land color(emma, x1) \land brown(x1))$$

emma **x1**



dog (emma) **color (emma, x1)** **brown (x1)**

语义网络应用——概念图表示法及其推理

概念图知识表示方法，是由美国的John F Sowa提出的面向自然语言处理的知识表示方法，它属于语义网络的范畴，具有结构简单、易读、表示范围广、接近自然语言、能确切地表示自然语言的语义等多种特点。

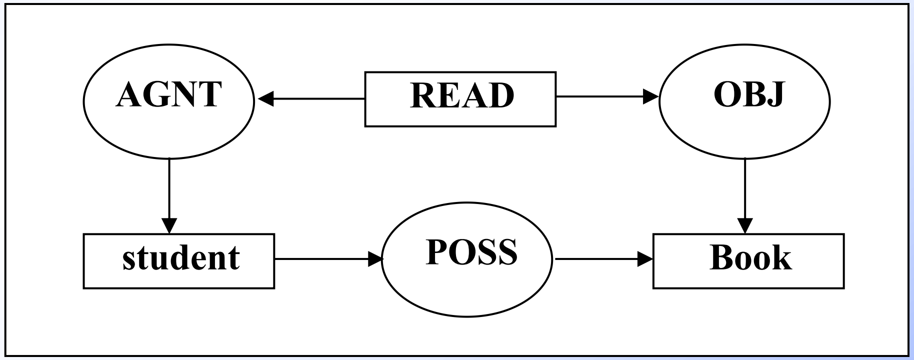


图1 No student read his own books的概念图

两个具有相同概念节点的概念图可以通过恒等线（用虚线“……”表示）把两个概念图连接在一起，形成一个合成图。没有恒等线的图叫做简单图。注意，用恒等线连接的两个概念必须概念类型相同，类型所指相同。因此，恒等线也叫做共同所指线。例如“No student read the teacher's book”的概念图如下：

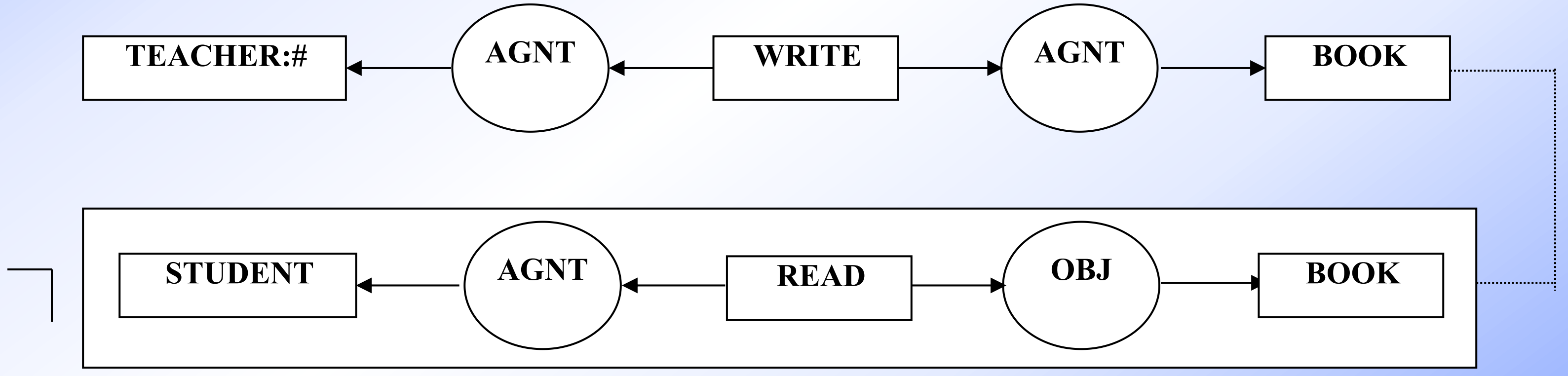


图2 No student read the teacher's book的概念图

一个概念图有显示和线性两种表示方法

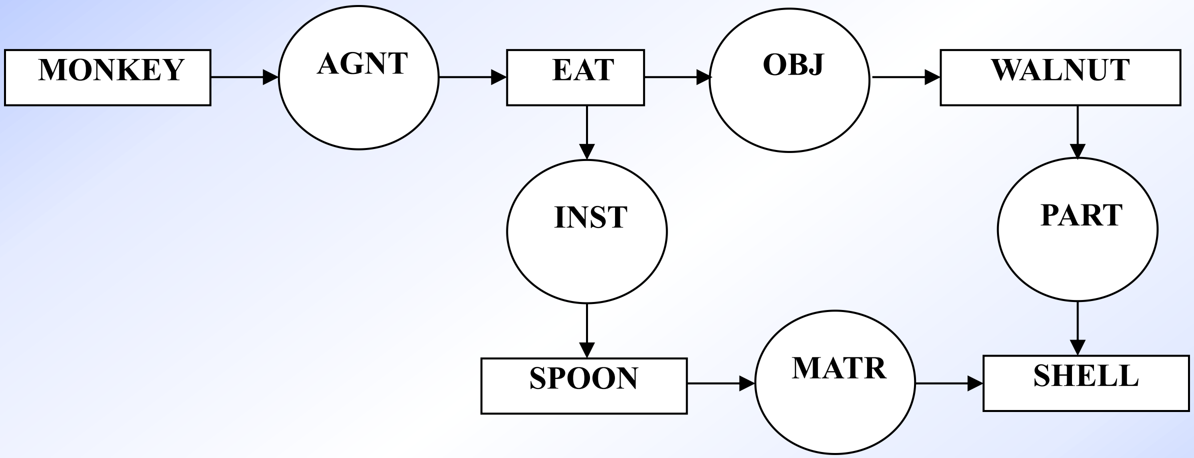


图3 a monkey eating a walnut with a spoon made out of the walnuts shell

概念图的线性形式

其线性形式如下：

EAT

（AGNT）→[MONKEY]

（OBJ）→[WALNUT：*x]

（INST）→[SPOON]→（MATR）→[SHELL]←（PART）←[WALNUT：*x]

概念图的存储结构

- 一个概念节点用具有4个属性的一个记录表示：

①标记：　　指出记录是一个概念；

②类型：　　指出概念类型记录；

③所指域：指出个体概念的所指域或一般概念的量词；

④关系表：指出当前概念所连的每一个关系记录。

- 一个关系节点用具有3个属性的记录表示：

①标记：　　指出记录是一个关系；

②类型：　　指出关系类型记录；

③弧指针：指出与关系相连（相联）的每个概念。

概念图的存储

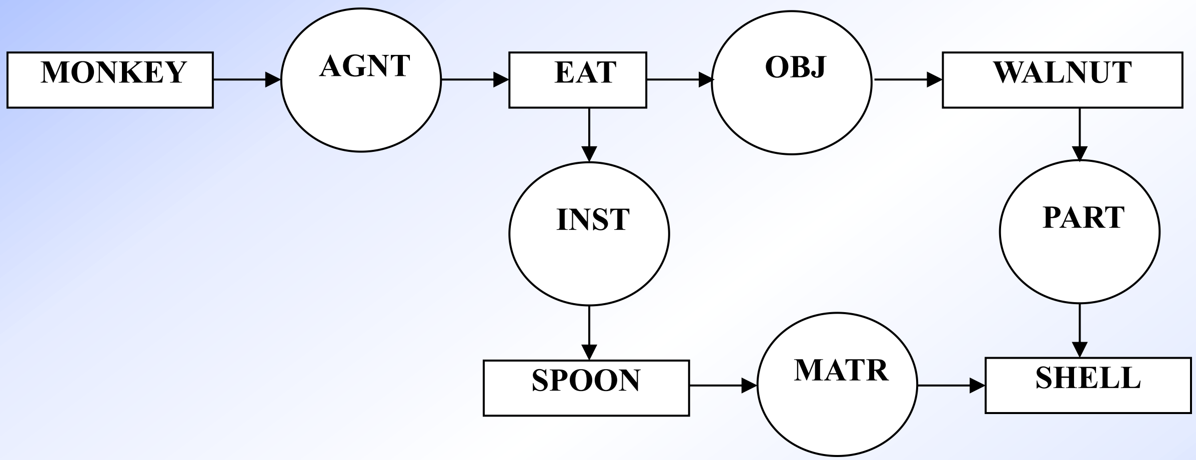
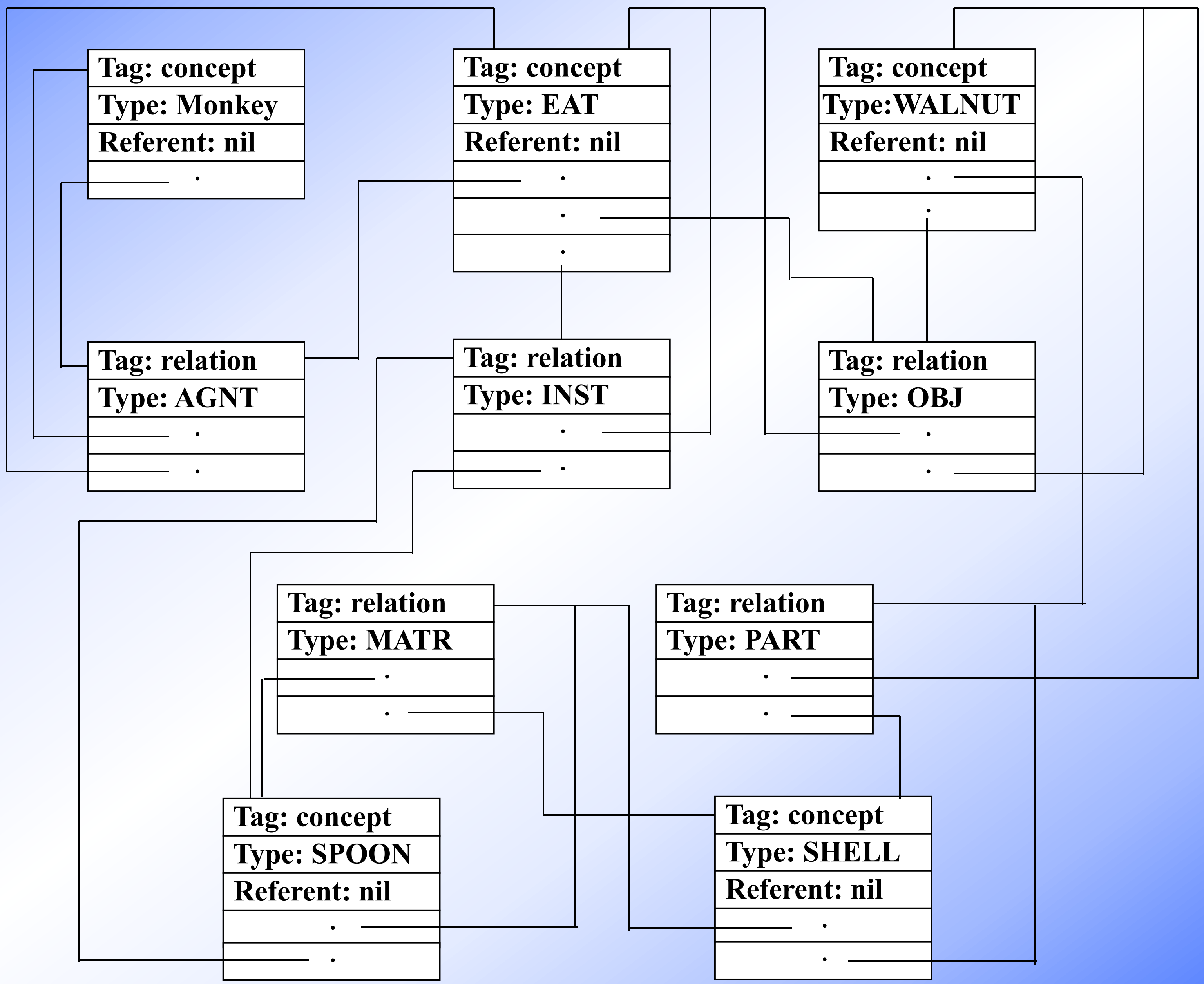


图3 a monkey eating a walnut with a spoon made out of the walnuts shell

图3所示概念图的逻辑结构如图4所示。

图4. 概念图的逻辑存储结构



一个简单概念图的prolog实现

概念图：

[PERSON:(john,joe,*)]←（AGNT）←[PLAY]→（OBJ）→[BALL]

相应的prolog事实表示如下：

```
concept(person:[pse,john,joe],[agnt],1000).
concept(play:g,[gnt,obj],1001).
concept(ball:g,[obj],1002).
relation(agnt,1001,1000,1003).
relation(obj,1001,1002,1004).
graph(dsl,[1000,1001,1002],[1003,1004],1005).
```

嵌入概念图的存储结构

嵌入的概念图是指某个概念的所指对象域，又是一个概念图。一个概念的所指对象也可以是多个嵌入的概念图。所有嵌入的概念图都出现在概念[PROPOSITION]的所指对象域中。其存储结构与简单图的类似，只是概念[PROPOSITION]的记录中有指向所嵌入图的指针。

[PERSON:Mary]←(AGNT)←[BELIEF]→(OBJ)

↓

PROPOSITION:[PERSON:{John,Joe,*}]←(AGNT)←[PLAY]→(OBJ)→[BALL]

图5

Prolog存储结构

其prolog事实又增加了以下几个：

concept(proposition:[gr,1005],[obj],1006).

concept(person:mary,[agnt],1007).

concept(belief:g,[agnt],1008).

relation(obj,1008,1006,1010).

relation(agnt,1008,1007,1009).

graphs(ds2,[1006,1007,1008],[1009,1010],1011).

概念图的匹配

- **概念图上的匹配**操作如下：

设u和v是两个概念图，若存在u的**一个子图**u'满足：

①u‘中的概念关系与v中对应的**概念关系相同**。

②对于u和v中的概念关系r连接的两个概念分别是c_i和c_j及d_i和d_j，**存在着最大的公共限制概念**e_i和e_j即$e_i \le c_i$ 和$e_i \le d_i$, $e_j \le c_j$ 和$e_j \le d_j$,且$e_i \ne$ABSURD，$e_J \ne$ABSURD。就说概念图v能匹配到概念图u。

- 应用以上定义在概念图u上和概念图v上进行下列替换：

θ_1=（$c_1 / e_1, c_2 / e_2, \ldots, c_n / e_n$）在图u上。

θ_2=（$d_1 / e_1, d_2 / e_2, \ldots, d_n / e_n$）在图v上。

概念图的投影运算

投影的定义：设u和v是两个概念图。如果**u≤v**，则存在一个u的子图u′和v同构。u′＝v→u，则称作v在u上的投影。

如果u′＝v→u，则下列3条成立：

(1)u′中的概念关系和v中的相同。

(2)u′中的概念$c_1,\ldots,c_n$是v中相应概念$d_1,\ldots,d_n$的某些**限制**。

(3)若v中的一个关系r连着两个概念d_i和d_j，则在u中，r连着概念c_i和 c_j。

例如，规则图v： IF [ANIMAL：*x]←(AGNT)←[FLIES]

THEN [ANIMAL：*x]→(TYPE)→[BIRD]

事实图u： [ANIMAL:peter]←(AGNT)←[FLIES] →(AGNT)→[LOVE]

则v在u上的投影图u′：

[ANIMAL:peter]←(AGNT)←[FLIES]

这个事实与规则的合一参数为：

$$\boldsymbol{\theta = \{peter/x\}}$$

那么，这个规则与事实匹配后的结论图：

[ANIMAL:peter] →(TYPE)→[BIRD]。

当然这个例子中只有一个合一参数。一般情况，θ是一个合一参数的集合，这个集合叫做一个替换。它的一般形式为：

$$\theta = \{a_1/x_1, \ldots, a_n/x_n\} \quad (n \geq 1)$$

其中，分子a_i是分母x_i（1 ≤i≤n）的一个特殊化，要用分子替换分母在规则中的出现。

概念图的最大连接运算

- **最大连接**是指一个在最大扩充的相容投影上的连接。它是两个原始图信息的混合，是在这两个原始图的最大连通子部分上的连接。

例如：[PERSON]←(AGNT)←[LIKE]→(OBJ)

→[ELEPHANT]]→(COLOR)→[GRAY]

和 [John]←(NAME)←[PERSON]←(AGNT)←[LIKE]

→(OBJ)→[MAMMAL]

的最大连接是：

[John]←(NAME)←[PERSON]←(AGNT)←[LIKE]

→(OBJ)→[ELEPHANT]→(COLOR)→[GRAY]

一个最大连接运算的算法（求u和v的最大连接）

(1)对v中的每个关系做下列循环：

a. 如果r不在u中，则找下一个关系。

b. 否则，设c_1和 c_2是u中被r所连的两个概念，d_1和 d_2是v中被r所连的两个概念。

如果c_1和 d_1是相容的，c_2和 d_2是相容的，则关系relation(r, e_1,e_2,—)放到结果图中。这里，e_1是c_1和 d_1的最大公共子类型，e_2是c_2和 d_2的最大公共子类型。否则，回溯到(1)。

(2)将v的余下部分连到结果图上。

(3)将u的余下部分连到结果图上。

这样，就得到了u和v的最大连接。

最大连接时，两个图的替换分别为：

图u中，$\theta=\{c_1/e_1,\ldots, c_n/e_n\}$

图v中，$\theta=\{d_1/e_1,\ldots, d_n/e_n\}$ $(n\geq1)$

最大连接算法中，对要合一的两个概念c_i和 d_i的条件比投影算法条件宽。投影算法中要求c_i是 d_i的限制，最大连接要求c_i和 d_I是相容的。

例如，[PERSON:‘John’]和[BOY:*x]在投影时不能合一。而在最大连接时，可合一成[BOY:‘John’]。

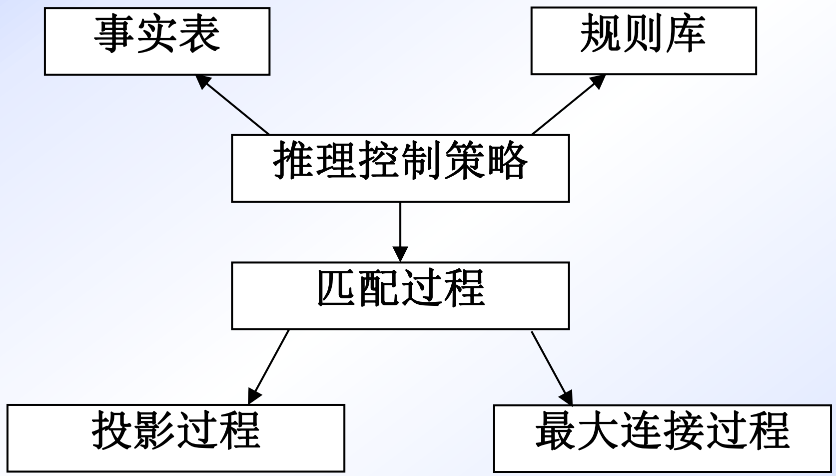
出基于图的匹配算法：

(1)设v是规则前提中的一个图，u是事实表中的一个图。如果，v=u，则匹配成功。

(2)如果u≤v，则调用投影运算过程，求出v在u上的投影，以及**合一参数θ**。则匹配成功。

(3)否则，调用最大连接运算过程。如果u和v的最大连接存在。则求出此最大连接，以及合一参数集合θ，匹配成功；反之，匹配失败。

整个推理过程中，各部分之间的相互关系可用下图说明：



推理机示意图

限制合一

- 定义：限制合一是以类型层次为基础，将两个图合并成一个图。

有关动物分类的部分类型层次如图6所示。

[TIGER]←(TYPE)←[ANIMAL]

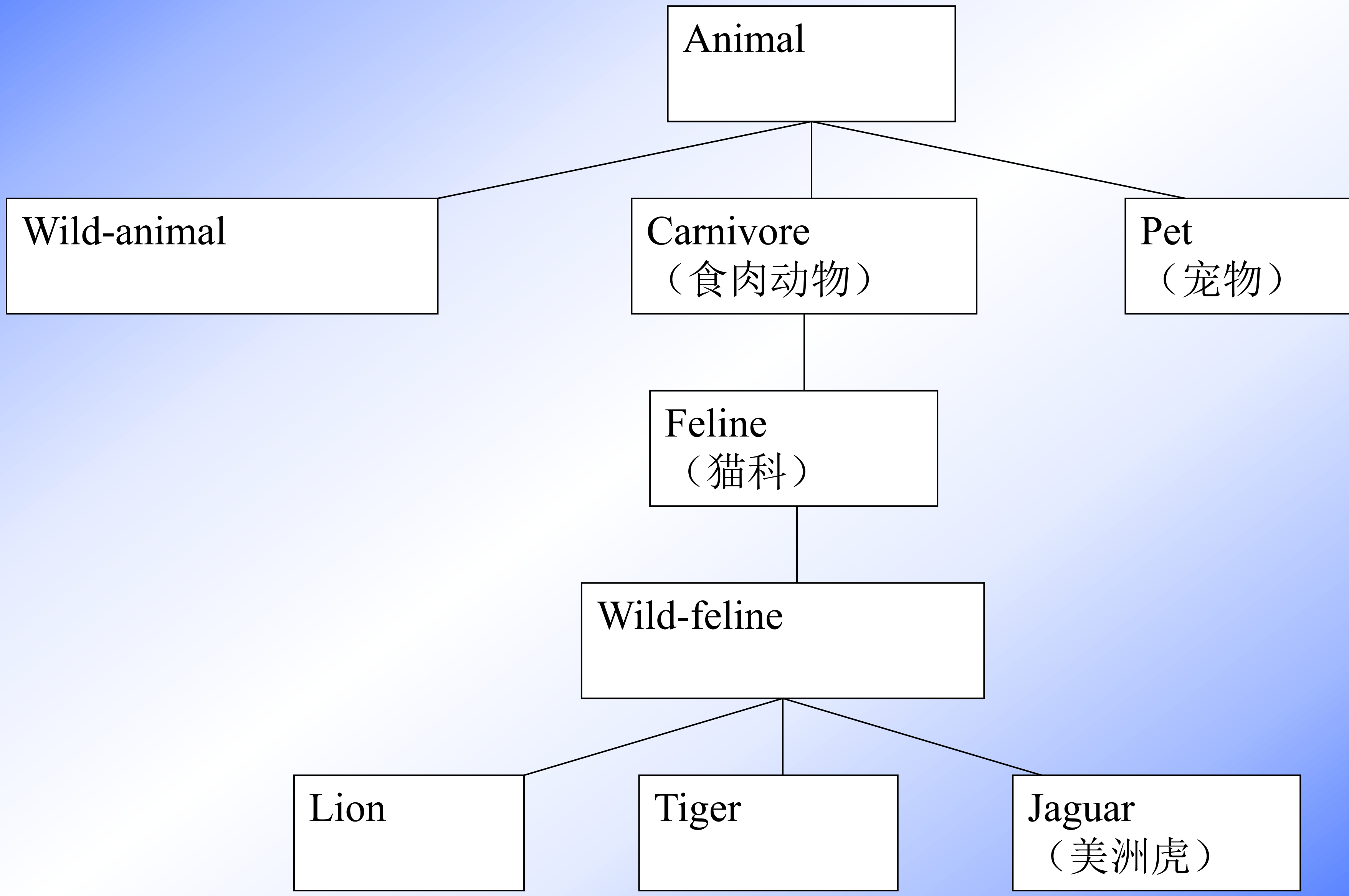
和　[LION]←(TYPE)←[ANIMAL]

可合一成：

[WILD-FELINE] ←(TYPE)←[ANIMAL]。

- [TIGER]和[LION]在最大连接和投影时都不能匹配。

类型层次


Animal
Wild-animal
Carnivore
（食肉动物）
Pet
（宠物）
Feline
（猫科）
Wild-feline
Lion
Tiger
Jaguar
（美洲虎）

- 两个类型标记的语义距离小于等于规定值时，方可合一。

根据上述定义，在上图中有：

SD（ANIMAL，WILD-ANLMAL）= 1

SD（CARNIVORE，WILD-ANIMAL）= 2

SD（WILD-ANIMAL，FELINE）= 3

- 假设规定值为2，则图

[TIGER]←(TYPE)←[ANIMAL]

和 [CARNIVORE]←(TYPE)←[ANIMAL]

不能合一，因为SD（CARNIVORE，TIGER）= 3。

- 但这时可以通过最大连接匹配。
- **投影匹配是精确推理，而最大连接和限制合一匹配实现了非精确推理。**

应用举例

- 语义网络与产生式系统结合运用

用概念图表示规则是一种简单直观的方法。规则是IF——THEN结构，而IF部分和THEN部分又都是概念图的集合。在IF部分和THEN部分，每个概念图之间都是‘AND’(∧)关系。所以，规则的一般形式可表示为：

IF：　(1)

⋮

(n)

THEN：　⋮

例1 建立如下规则R：如果动物会飞，而且会下蛋，则该动物是鸟。这条规则用概念图表示如下：

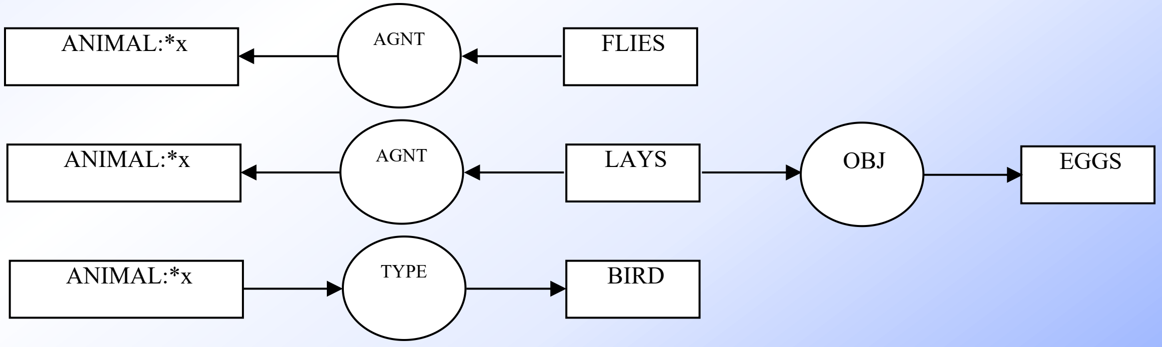


图7 规则R的概念图

[例]：一个人是A国公民，当且仅当下列条件之一成立：

①他（她）生在A国；

②他（她）的父亲是A 国公民；

③他（她）加入A国国籍。

已知李朋出生在中国，并且他的孩子叫李洪，问谁是中国公民？

RULE1：[CITIZEN：x]←(MEMB)←[COUNTRY：A] ⇐
[PERSON：x] ←(AGNT)←[BORN]→(LOC) →[COUNTRY：A]

RULE2：[CITIZEN：x]←(MEMB)←[COUNTRY：A] ⇐
[PERSON：x] ←(CHLD)← [PERSON：y]
and [CITIZEN：y]←(MEMB)←[COUNTRY：A]

RULE3：[CITIZEN：x]←(MEMB)←[COUNTRY：A] ⇐
[PERSON：x]←(RCPT)←[NATURALIZE]→(LOC) →[COUNTRY：A]

FACT：李朋出生在中国，并且他的孩子叫李洪。

[PERSON：LI PENG]←(AGNT)←[BORN] →(LOC)→[COUNTRY：CHINA]

↓

（CHLD）

↓

[GIRL：LI HONG]

GOAL：“谁是中国公民？”

[PERSON：？] ←(MEMB)←[COUNTRY：CHINA]

匹配和推理

（1）首先把规则1的前提与事实匹配，得到替换x/LI PENG。将替换作用于规则1 得到：

[CITIZEN：LI PENG] ←(MEMB)←[COUNTRY：CHINA]

（2）把规则2的前提与事实及RESULT1匹配，得到替换x/LI HONG，y/LI PENG。将替换作用于规则2得到：

[CITIZEN：LI HONG] ←(MEMB)←[COUNTRY：CHINA]

7.3 Alternative Representations and Ontologies

7.3.1 Brooks’ Subsumption Architecture

（包容结构）

- Intelligence, Brooks claims, is the product of the interaction between an appropriately designed system and its environment.

- Furthermore, Brooks espouses（信奉）the view that intelligent behavior emerges（涌现）from the interactions of architectures of organized simpler behaviors: his subsumption architecture

罗德尼·布鲁克斯 Rodney Brooks

美国著名机器人制造专家罗德尼·布鲁克斯(Rodney Brooks)。包容体系结构的发明者，MIT's 电脑科学和人工智能实验室（MIT AI Lab）的现任领导。20世纪90年代设计了第一个火星机器人。Rodney Brooks在1986年发表的论文中提到的**包容式结构**表明了基于行为的编程方法的正式起源。

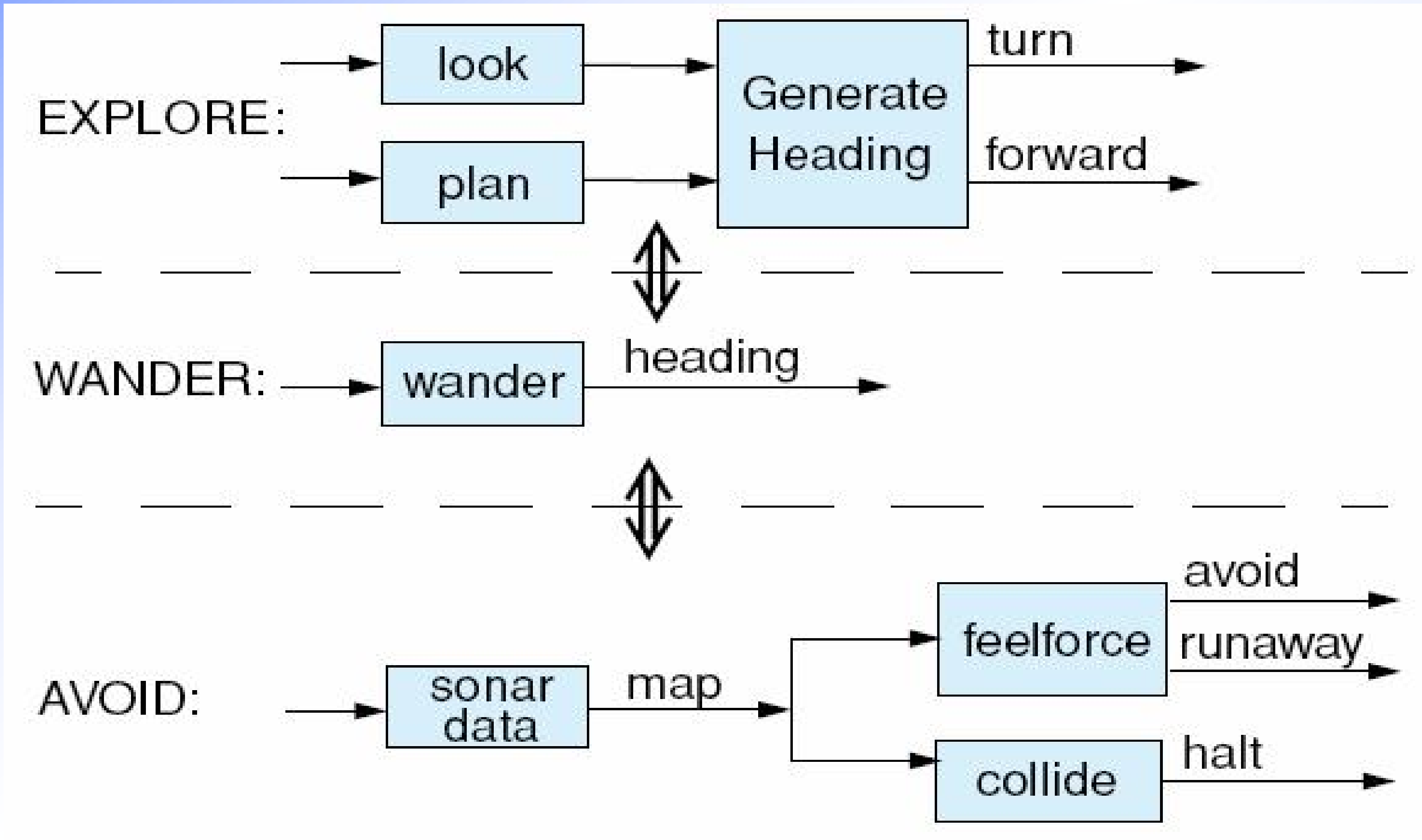
有“坏小子”之称的罗德尼·布鲁克斯出身于澳大利亚，MIT人工智能实验室的教授。从80年代起，他就反对“机器人必须先会思考，才能做事”的信条。为了证实自己的观点，他研制出一系列的异形机器人。这些机器人没有思考能力，但却无所不能，比如能偷桌上的苏打罐，穿越四周发烫的地面等。

——机器人领域最有争议的人物

从科学家的角度， Brooks 解释了许多科幻作家和爱好者关注的问题，机器人能思考、感觉、活着吗？人工智能何时不再是人工的？有意识和无意识的区别是什么？

Dr. Brooks在南澳大利亚Flinders 大学获得数学学位，在斯坦福大学获计算机博士学位，美国人工智能研究协会(AAAI)的创建者，美国高级科学协会(AAAS)的会员。

The functions of the three-layered subsumption architecture The layers are described by the AVOID, WANDER, and EXPLORE behaviours.



1. There is a problem of the sufficiency（充足性）of information at each system level
2. If there exists absolutely no ‘knowledge’ or ‘model’ of the complete environment, how can the limited input on the local situation be sufficient for determination of globally acceptable actions?
3. How can a purely reactive（反应）component with very limited state learn from its environment?
4. There is a problem of scale.

(Now 6 layers, even 10 layers ?)

作业

- 3
- 5
- 9
- 13
- 14