The Introduction To Artificial Intelligence

Yuni Zeng yunizeng@zstu.edu.cn

2022-2023-1

The Introduction to Artificial Intelligence

- Part I Brief Introduction to AI & Different AI tribes
- Part II Knowledge Representation & Reasoning

- **Brief Review**

1.3 Knowledge Representation & Reasoning

Predicate Logic

- Definition: A statement of form $P(x_1, x_2, \cdots, x_n)$ is the value of the propositional function P. Here, $(x_1, x_2, \cdots, x_n)$ is an n-tuple and P is a predicate.

- You can think of a propositional function as a function that

  (1) Evaluates to true or false

  (2) Take one or more arguments

  (3) Expresses a predicate involving the argument(s).

  (4) Becomes a proposition when values are assigned to the arguments.

1.3 Knowledge Representation & Reasoning

Predicate Logic

- Consider the previous example. Does it make sense to assign to x the value “blue”?

- Intuitively, *the universe of discourse* is the set of all things we wish to talk about; that is, the set of all objects that we can sensibly assign to variable in a propositional function.

- What would be the universe of discourse for propositional function $P(x)$ = “The test will be on x the 23rd” be ?

1.3 Knowledge Representation & Reasoning

Quantifiers

- A predicate becomes a proposition when we assign it fixed values.

- However, another way to make a predicate into a proposition is to *quantify* it. That is, the predicate is true (or false) for *all* possible values in the universe of discourse or for *some* value(s) in the universe of discourse.

- Such *quantification* can be done with two quantifiers: the *universal* quantifier and the *existential* quantifier.

1.3 Knowledge Representation & Reasoning

Quantifiers

- Definition: The universal quantification of a predicate $P(x)$ is the proposition "$P(x)$ is true for all values of x in the universe of discourse". We use the notation

$$\forall x P(x)$$

which can be read "for all x".

- If the universe of discourse is finite, say $\{n_1, n_2, \cdots, n_k\}$, then the universal quantifier is simply the conjunction of all elements:

$$\forall x P(x) \Leftrightarrow P(n_1) \wedge P(n_2) \wedge P(n_3) \wedge \cdots \wedge P(n_k)$$

1.3 Knowledge Representation & Reasoning

Quantifiers

- Definition: The *existential quantification* of a predicate $P(x)$ is the proposition "There exist an x in the universe of discourse such $P(x)$ is true". We use the notation

$$\exists x P(x)$$

which can be read "there exist an x".

- Again, If the universe of discourse is finite, say $\{n_1, n_2, \cdots, n_k\}$, then the *existential* quantifier is simply the disjunction of all elements:

$$\exists x P(x) \Leftrightarrow P(n_1) \lor P(n_2) \lor P(n_3) \lor \cdots \lor P(n_k)$$

1.3 Knowledge Representation & Reasoning

Mixing Quantifiers

- Existential and universal quantifiers can be used together to quantify a predicate statement; for example,

$$\forall x \exists y P(x, y)$$

is perfectly valid.

- $\forall$x $\forall$y is the same as $\forall$y $\forall$x
- $\exists$x $\exists$y is the same as $\exists$y $\exists$x

- However, you must be careful – it must be read left to right.
- For example, $\forall x \exists y P(x, y)$ is not equivalent to $\exists y \forall x(x, y)$.
- Thus, ordering is important.

1.3 Knowledge Representation & Reasoning

Mixing Quantifiers

- Just as we can use negation with proposition, we can use them with quantified expressions.
- Let $P(x)$ be a predicate. Then the following hold.

$$\neg \forall x P(x) \equiv \exists x \neg P(x)$$

$$\neg \exists x P(x) \equiv \forall x \neg P(x)$$

- This is essentially a quantified version of De Morgan's Law (in fact if the universe of discourse if finite, it is exactly De Morgan's law)
- $\forall x P(x) \Leftrightarrow P(n_1) \wedge P(n_2) \wedge P(n_3) \wedge \cdots \wedge P(n_k)$
- $\exists x P(x) \Leftrightarrow P(n_1) \vee P(n_2) \vee P(n_3) \vee \cdots \vee P(n_k)$

1.3 Knowledge Representation & Reasoning

Translation from English to logic

Formula	Description
$\forall x\ frog(x) \Rightarrow green(x)$	All frogs are green
$\forall x\ frog(x) \wedge brown(x) \Rightarrow big(x)$	All brown frogs are big
$\forall x\ likes(x, cake)$	Everyone likes cake
$\neg\forall x\ likes(x, cake)$	Not everyone likes cake
$\neg\exists x\ likes(x, cake)$	No one likes cake
$\exists x\ \forall y\ likes(y, x)$	There is something that everyone likes
$\exists x\ \forall y\ likes(x, y)$	There is someone who likes everything
$\forall x\ \exists y\ likes(y, x)$	Everything is loved by someone
$\forall x\ \exists y\ likes(x, y)$	Everyone likes something
$\forall x\ customer(x) \Rightarrow likes(bob, x)$	Bob likes every customer
$\exists x\ customer(x) \wedge likes(x, bob)$	There is a customer whom bob likes
$\exists x\ baker(x) \wedge \forall y\ customer(y) \Rightarrow mag(x, y)$	There is a baker who likes all of his customers

Homework-2

Mixing Quantifiers

- Express the statement “there is a number x such that when it is added to any number, the result is that number, and if it is multiplied by any number, the result is x ” as a logical expression.

- Solution:

Homework-2

Mixing Quantifiers

- Express the statement "there is a number x such that when it is added to any number, the result is that number, and if it is multiplied by any number, the result is x" as a logical expression.
- Solution:

(1) Let $P(x, y)$ be the expression "$x + y = y$".

(2) Let $Q(x, y)$ be the expression "$xy = x$".

(3) Then the expression is

$$\exists x \forall y (P(x, y) \land Q(x, y))$$

(4) Over what universe(s) of discourse does this statement hold?

(5) This is the additive identity law and holds for $\mathbb{N}, \mathbb{Z}, \mathbb{R}, \mathbb{Q}$ but does not hold for $\mathbb{Z}^+$

Homework-3

- Let $P(x, y)$ denote "x is a factor of y" where $x \in \{1,2,3, \cdots\}$ and y $\in \{1,2,3, \cdots\}$. Let $Q(y)$ denote "$\forall x[P(x, y) \rightarrow ((x = y) \lor (x = 1))]$" . When is $Q(y)$ true?

Homework-3

- Let $P(x, y)$ denote "x is a factor of y" where $x \in \{1,2,3, \cdots\}$ and y $\in \{1,2,3, \cdots\}$. Let $Q(y)$ denote "$\forall x[P(x, y) \rightarrow ((x = y) \vee (x = 1))]$" . When is $Q(y)$ true?

- x is a factor of y: $y = kx, k$ is a integer, which means there is no remainder when y is divided by x.
- For example, 2 $\times$ 3 = 6. Therefore, 2 and 3 are factors of 6. There is no remainder when 6 is divided by either 2 or 3.

- Answer: Only when y is a prime number.

1.3 Knowledge Representation & Reasoning

- What is knowledge representation?
- Propositional Logic
- Predicate Logic
- *Production-rule System*
- Frame-Based System
- State Space System
- Knowledge graph

1.3 Knowledge Representation & Reasoning

Production-rule System

- It was first proposed by the American mathematician E. Post in 1943.

- In 1972, Newell and Simon developed rule-based production systems in the study of human cognitive models.

- to represent facts, rules and their uncertainty measures, and is suitable for representing factual knowledge and regular knowledge.

1.3 Knowledge Representation & Reasoning

Production-rule System

- Production representation of certainty rule knowledge

Basic Form: IF P THEN Q

Or: $P \rightarrow Q$

For example:

IF an animal can fly AND can lay eggs THEN it is a bird.

- Production representation of uncertainty rule knowledge

Basic Form: IF P THEN Q (Certification factor)

Or: $P \rightarrow Q$ (Certification factor)

For example:

IF have a fever THEN catch a cold (0.6).

1.3 Knowledge Representation & Reasoning

Production-rule System

- Proposition

  E.g., Snow is white.   John likes AI.

- Representation in computer:

  Ternary:

  (attribute, object, value), (relation, object1, object2)

  E.g., (color, snow, white)   (like, John, AI)

  Quaternion:

  (attribute, object, value, certification factor), (relation, object1, object2, certification factor)

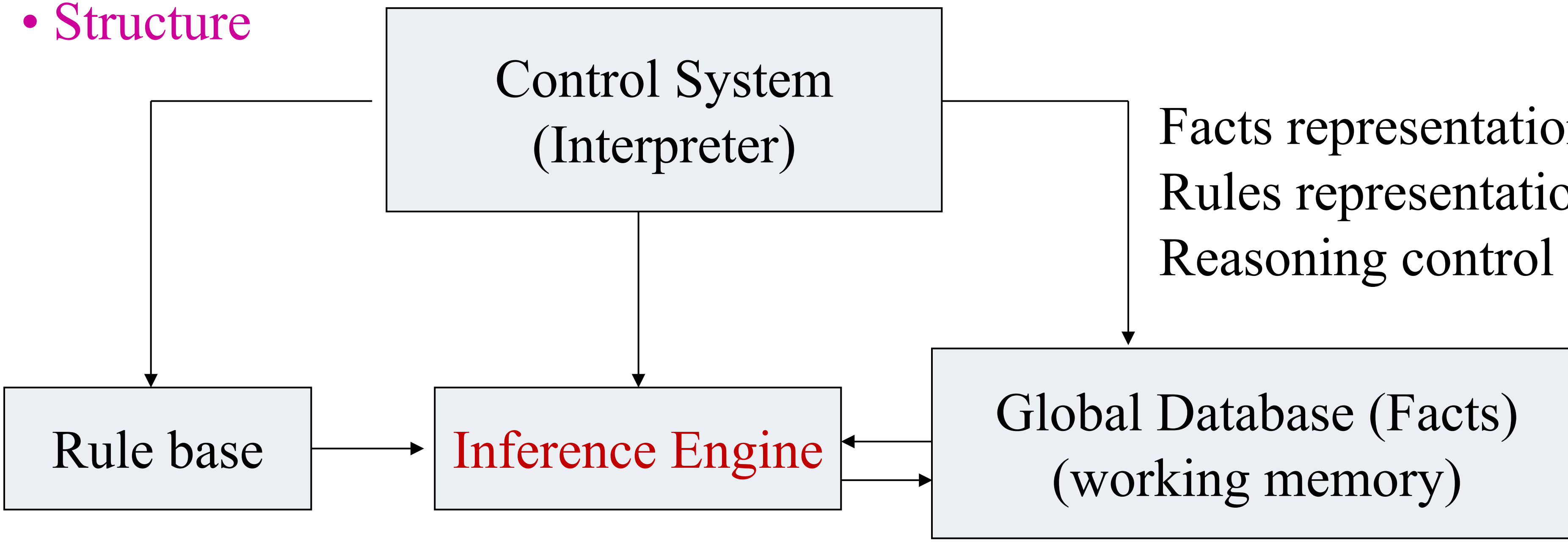
  E.g.: Mr. Li may be 40 years old. (age, Mr. Li, 40, 0.8)

  Lao Wang and Lao Li are unlikely friends. (friends, Wang, Li, 0.1)

1.3 Knowledge Representation & Reasoning

Production-rule System

- Structure

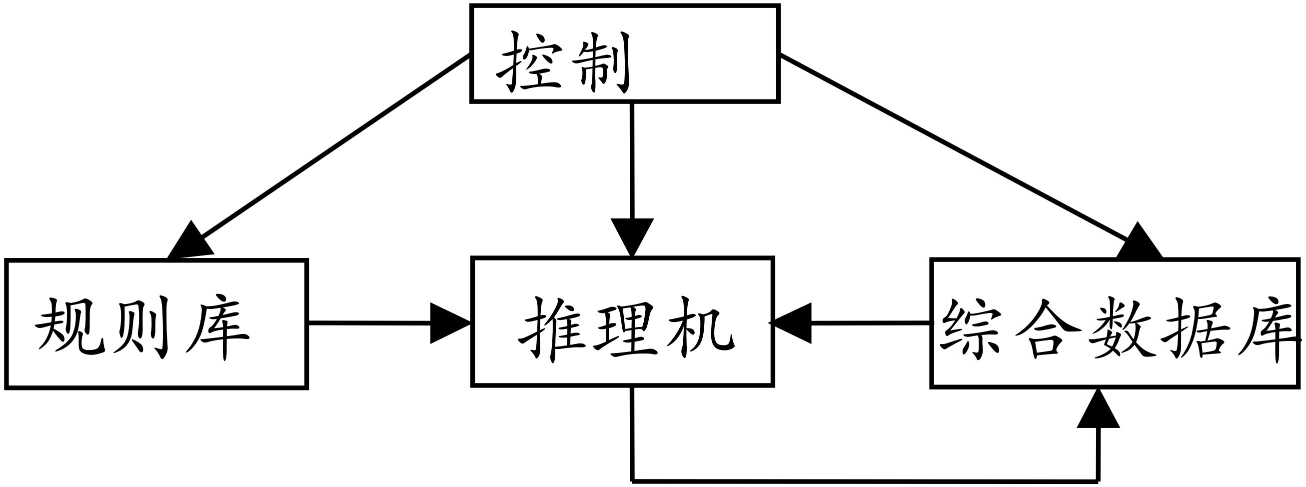


- Procedure

Rule Matching → Conflict Resolution → Rule Execution

Stop Conditions

1.3 Knowledge Representation & Reasoning



产生式系统的基本结构

产生式系统

控制系统要做以下工作：

（1）从规则库中选择与综合数据库中的已知事实进行匹配。

（2）匹配成功的规则可能不止一条，进行冲突消解。

（3）执行某一规则时，如果其右部是一个或多个结论，则把这些结论加入到综合数据库中；如果其右部是一个或多个操作，则执行这些操作。

（4）对于不确定性知识，在执行每一条规则时还要按一定的算法计算结论的不确定性。

（5）检查综合数据库中是否包含了最终结论，决定是否停止系统的运行。

1.3 Knowledge Representation & Reasoning

- Production-rule System --- Example, ANIMAL RECOGNITION SYSTEM
  - A production system for the recognition of seven animals: tiger, leopard, zebra, giraffe, ostrich, penguin and albatross







1.3 Knowledge Representation & Reasoning

- Production-rule System --- Example, ANIMAL RECOGNITION SYSTEM
  - Rule base

r_1: IF The animal has hair Then The animal is a mammal

r_2: IF The animal has milk Then The animal is a mammal

r_3: IF The animal has feathers Then The animal is a bird

r_4: IF The animal can fly AND can lay eggs Then The animal is a bird

r_5: IF The animal eats meat Then The animal is a carnivore

r_6: IF The animal has canine teeth AND has claws AND eye on the front Then The animal is a carnivore

r_7: IF The animal is a mammal AND has hoofed Then The animal is an ungulate

1.3 Knowledge Representation & Reasoning

Production-rule System --- Example, ANIMAL RECOGNITION SYSTEM

- Rule base

r_8: IF The animal is a mammal AND is ruminant Then The animal is an ungulate

r_9: IF The animal is a mammal AND is a carnivore AND in tan AND has dark spots on the body Then The animal is a leopard

r_{10}: IF The animal is a mammal AND is a carnivore AND in tan AND has black stripe on the body Then The animal is a tiger

r_{11}: IF The animal is an ungulate AND has long neck AND has long legs AND has dark spots on the body Then The animal is a giraffe

r_{12}: IF The animal is an ungulate AND has dark spots on the body Then The animal is a zebra

1.3 Knowledge Representation & Reasoning

- Production-rule System --- Example, ANIMAL RECOGNITION SYSTEM

r_9: **IF** 该动物是哺乳动物 **AND** 是食肉动物 **AND** 是黄褐色 **AND** 身上有暗斑点 **THEN** 该动物是金钱豹

r_{10}: **IF** 该动物是哺乳动物 **AND** 是食肉动物 **AND** 是黄褐色 **AND** 身上有黑色条纹 **THEN** 该动物是虎

r_{11}: **IF** 该动物是有蹄类动物 **AND** 有长脖子 **AND** 有长腿 **AND** 身上有暗斑点 **THEN** 该动物是长颈鹿

r_{12}: **IF** 该动物有蹄类动物 **AND** 身上有黑色条纹 **THEN** 该动物是斑马

r_{13}: **IF** 该动物是鸟 **AND** 有长脖子 **AND** 有长腿 **AND** 不会飞 **AND** 有黑白二色 **THEN** 该动物是鸵鸟

r_{14}: **IF** 该动物是鸟 **AND** 会游泳 **AND** 不会飞 **AND** 有黑白二色 **THEN** 该动物是企鹅

r_{15}: **IF** 该动物是鸟 **AND** 善飞 **THEN** 该动物是信天翁

1.3 Knowledge Representation & Reasoning

Production-rule System --- Example, ANIMAL RECOGNITION SYSTEM

- **设已知初始事实存放在综合数据库中：**

  该动物身上有暗斑点、长脖子、长腿、奶、蹄

- **推理机构的工作过程：**

  (1) 从规则库中取出r1，检查其前提是否可与综合数据库中的已知事实匹配。匹配失败则r1不能被用于推理。然后取r2进行同样的工作。匹配成功则r2被执行。

  ·综合数据库：该动物身上有暗斑点、长脖子、长腿、奶、蹄、哺乳动物

  (2) 分别用r3、r4、r5、r6综合数据库中的已知事实进行匹配，均不成功。r7匹配成功，执行r7。

  ·综合数据库： 该动物身上有暗斑点、长脖子、长腿、奶、蹄、哺乳动物、有蹄类动物

  (3) r11匹配成功，并推出“该动物是长颈鹿”

(3) r_{11} is matched successfully, and "This animal is a giraffe" is launched.

1.3 Knowledge Representation & Reasoning

Production-rule System

产生式表示法的优点

(1) 自然性

(2) 模块性

(3) 有效性

(4) 清晰性

产生式表示法的缺点

(1) 效率不高

(2) 不能表达结构性知识

适合产生式表示的知识

(1) 领域知识间关系不密切，不存在结构关系。

(2) 经验性及不确定性的知识，且相关领域中对这些知识没有严格、统一的理论。

(3) 领域问题的求解过程可被表示为一系列相对独立的操作，且每个操作可被表示为一条或多条产生式规则。

1.3 Knowledge Representation & Reasoning

- What is knowledge representation?
- Propositional Logic
- Production-rule System
- *Frame-Based System*
- State Space System
- Knowledge graph

1.3 Knowledge Representation & Reasoning

Frame-Based System

- In 1975, Minsky proposed the frame theory: the various knowledge of people is stored in memory in a structure similar to the frame.

- A structured knowledge representation method has been applied in many systems.

1.3 Knowledge Representation & Reasoning

Frame-Based System

- **框架（frame）**：一种描述所论对象（一个事物、事件或概念）属性的数据结构。
- 一个框架由若干个被称为“槽”（slot）的结构组成，每一个槽又可根据实际情况划分为若干个“侧面”（faced）。
- 一个槽用于描述所论对象某一方面的属性。
- 一个侧面用于描述相应属性的一个方面。
- 槽和侧面所具有的属性值分别被称为槽值和侧面值。

Frame-Based System

<Frame name>

Slot Name1: Facet Name 11

Facet Name 12

⋮

Facet Name 1m

Slot Name 2: Facet Name 21

Facet Name 22

⋮

Facet Name 2m facet value 2m1, ⋯, facet value 2mpm

⋮

<框架名>

槽名1: 侧面名$_{11}$ 侧面值$_{111}$，⋯，侧面值$_{11P1}$

⋮ ⋮

侧面名$_{1m}$ 侧面值$_{1m1}$，⋯，侧面值$_{1mPm}$

槽名n: 侧面名$_{n1}$ 侧面值$_{n11}$，⋯，侧面值$_{n1P1}$

⋮

侧面名$_{nm}$ 侧面值$_{nm1}$，⋯，侧面值$_{nmPm}$

约束: 约束条件$_1$

⋮

约束条件$_n$

1.3 Knowledge Representation & Reasoning

- Frame-Based System

Frame name: < Teacher>

Name: Unit (the first name, the last name)

Age: Unit (-year-old)

Sex: Range (male, female)， if missing, male

Title: Range (professor, associate professor, lecturer, assistant), if missing, lecturer.

Department: Organization

Address: <address frame >

Salary: <salary frame>

The date of starting work: Unit (year-month)

Deadline of work: Unit (year-month), if missing, today

1.3 Knowledge Representation & Reasoning

Frame-Based System

Frame name: < Teacher-1>

Name: Bing Xia

Age: 36

Sex: female

Title: associate professor

Department: Department of Computer Science

Address: <adr-1>

Salary: <sal-1>

The date of starting work: 1988.09)

Deadline of work: 1996.07

框架名：〈教师-1〉
姓名：夏冰
年龄：36
性别：女
职称：副教授
部门：计算机系软件教研室
住址：〈adr-1〉
工资：〈sal-1〉
开始工作时间：1988，9
截止时间：1996，7

1.3 Knowledge Representation & Reasoning

Frame-Based System

- **将下列一则地震消息用框架表示：**“某年某月某日，某地发生6.0级地震，若以膨胀注水孕震模式为标准，则三项地震前兆中的波速比为0.45，水氡含量为0.43，地形改变为0.60。
- **解：**地震消息用框架如下图所示

框架名：〈地震〉

地　　点：某地

日　　期：某年某月某日

震　　级：6.0

波 速 比：0.45

水氡含量：0.43

地形改变：0.60

1.3 Knowledge Representation & Reasoning

Frame-Based System

- It is easy to express structural knowledge, and can express the internal structural relations of knowledge and the relations between knowledge.

- One frame can inherit the slot value of another frame, and can also be supplemented and modified.

- is consistent with the thinking activity of people when they observe things

1.3 Knowledge Representation & Reasoning

- What is knowledge representation?
- Propositional Logic
- Production-rule System
- Frame-Based System
- State Space System
- Knowledge graph

1.3 Knowledge Representation & Reasoning

State Space System

- State space: A system of symbols to represent knowledge or questions by state variables and operational symbols.

$$(S, O, S_0, G)$$

- S: The state set
- O: The operations set
- S_0: Contain the initial state
- G: Some specific states or path information description satisfying certain condition

1.3 Knowledge Representation & Reasoning

State Space System

- The solution path from node S_0 to note G
- One solution: one finite O sequence, like

$$S_0 \xrightarrow{O_1} S_1 \xrightarrow{O_2} S_2 \xrightarrow{O_3} \cdots \xrightarrow{O_k} G$$

- This means $O_1, \cdots O_k$ is a solution path of state space

1.3 Knowledge Representation & Reasoning

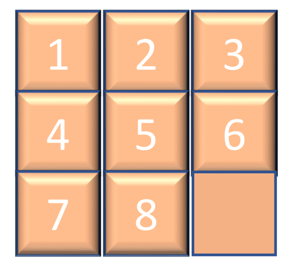
State Space System

- A simple Example: The 8-puzzle

HOW to find a path from the initial state to the goal ?

Start

Goal



1.3 Knowledge Representation & Reasoning

State Space System

- A simple Example: The 8-puzzle

Start

S_0:

2	5	1
4		8
7	3	6

Goal

G:

1	2	3
4	5	6
7	8	

O: move up, down, left, right (4 operations)

S: The state set

1.3 Knowledge Representation & Reasoning

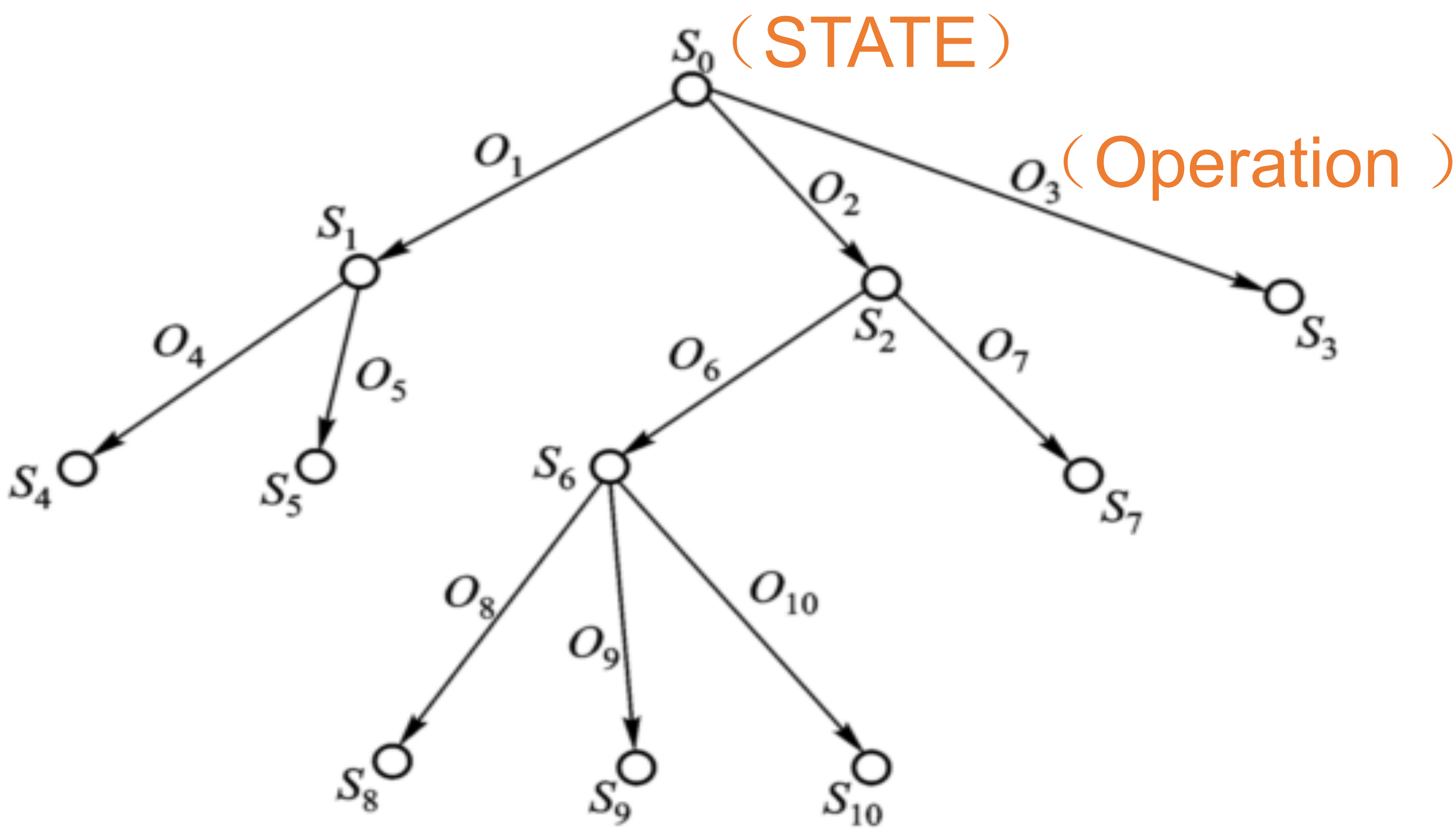
State Space System

- The state space can be described by a directed graph. The nodes in the graph represent the states of the problem, and the arcs or edges of the graph represent the relationships between the states.
- The initial state is the root of the graph.

- In state space system, to find one finite operation sequence from one state to anther is equivalent to find a path in the directed graph.

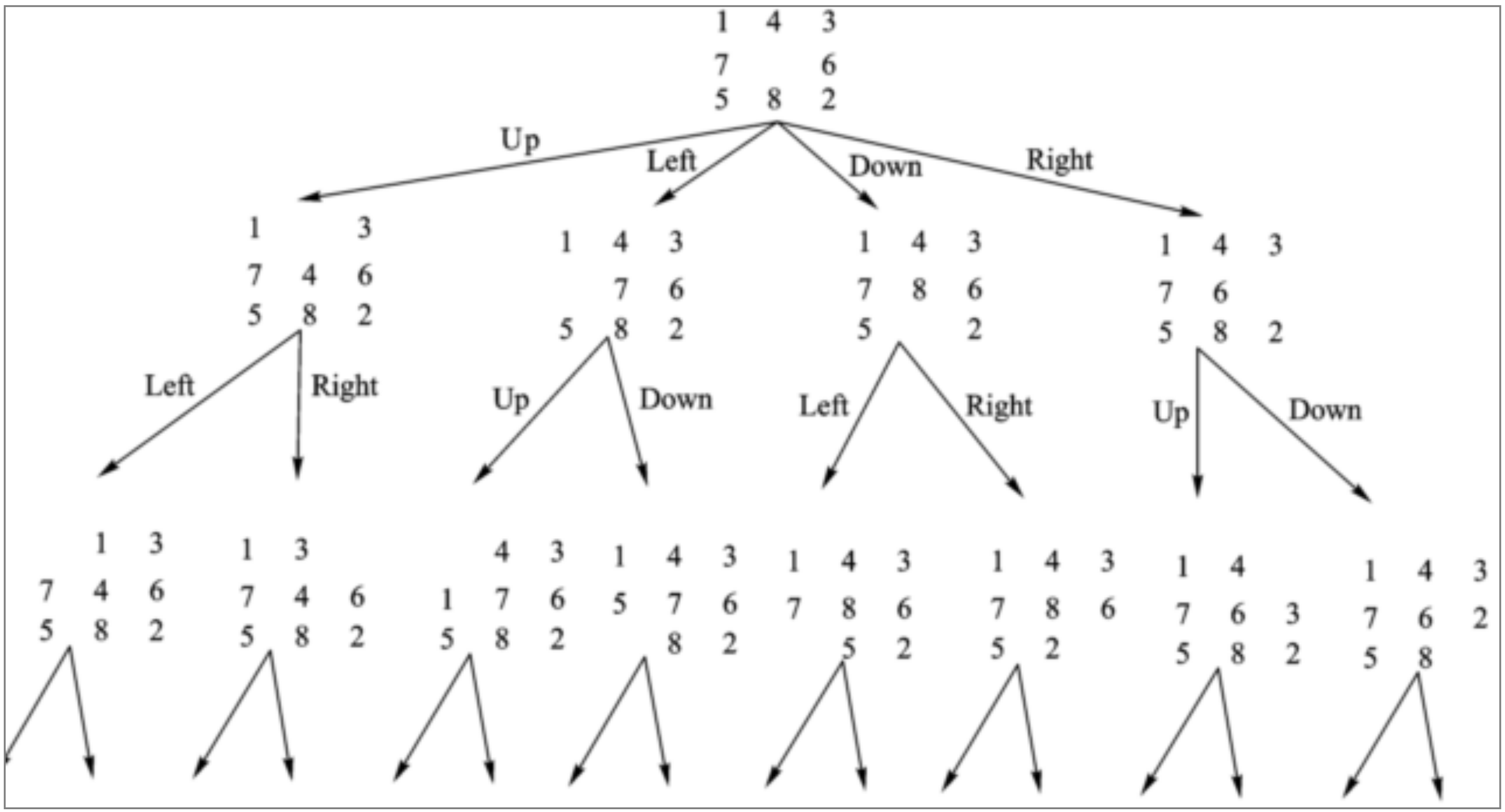
1.3 Knowledge Representation & Reasoning

- State Space System Based on Graph



1.3 Knowledge Representation & Reasoning

State Space System Based on Graph



Directed graph of the 8-puzzle

1.3 Knowledge Representation & Reasoning

State Space System -- Example 2

- Traveling salesman problem (TSP)
  - A salesman travels from his starting point to several cities to sell his product, and then returns to his starting point. Each city is required to walk once, and only once
  - "Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city exactly once and returns to the origin city?"

1.3 Knowledge Representation & Reasoning

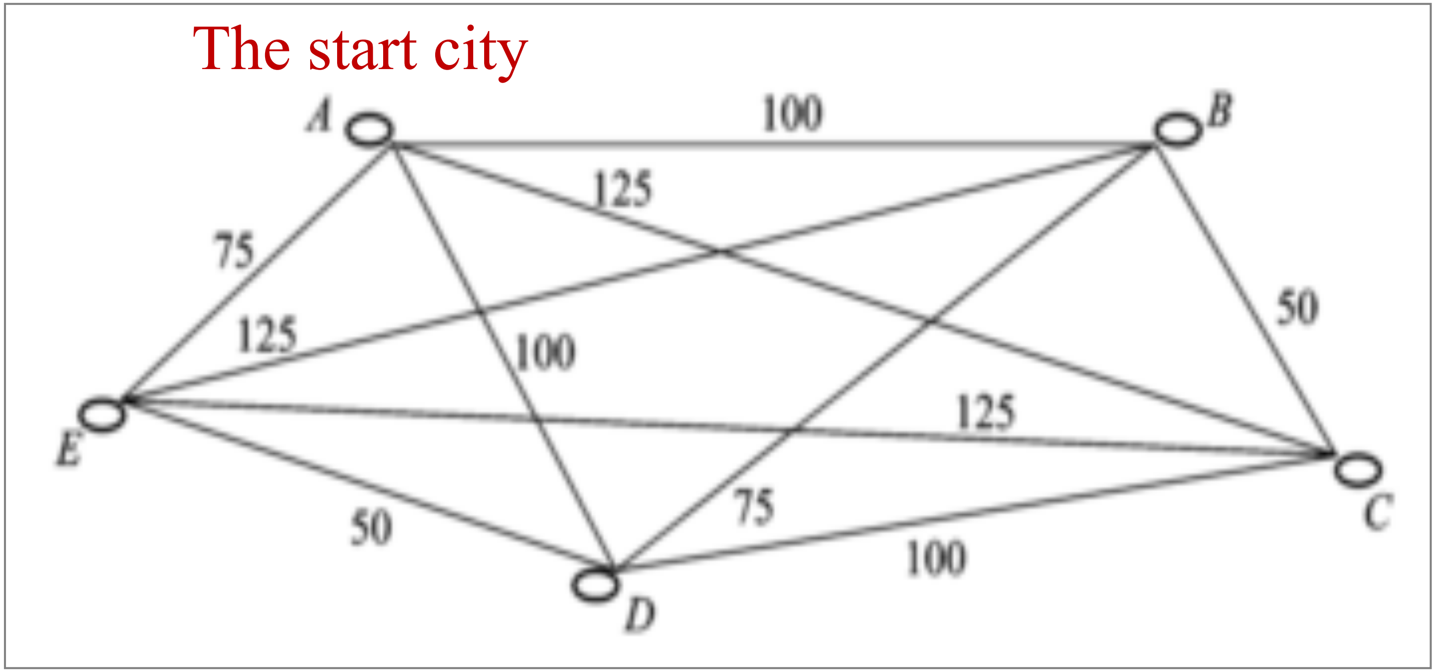
State Space System -- Example 2

- State Space Graph of Traveling Salesman Problem (TSP)
  - Nodes : Cities
  - Edges : Distance or traveling fees between two cities
  - Root node: the start city

1.3 Knowledge Representation & Reasoning

State Space System -- Example 2

- State Space Graph of Traveling Salesman Problem (TSP)

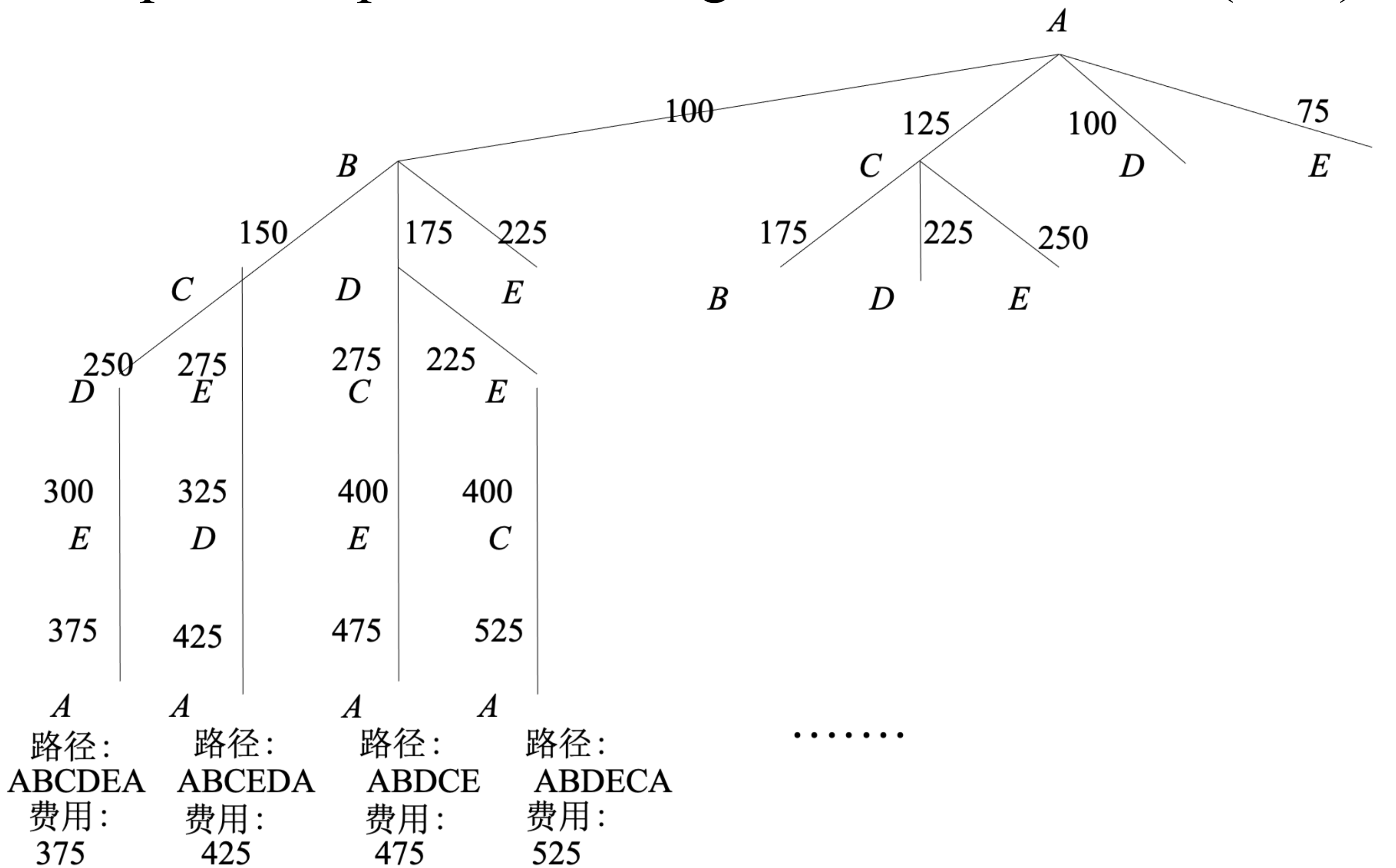


- Possible path: (A,B,C,D,E,A)

1.3 Knowledge Representation & Reasoning

State Space System -- Example 2

- State Space Graph of Traveling Salesman Problem (TSP)



1.3 Knowledge Representation & Reasoning

- What is knowledge representation?
- Propositional Logic
- Production-rule System
- Frame-Based System
- State Space System
- *Knowledge graph*

1.3 Knowledge Representation & Reasoning

Knowledge graph

- knowledge graph (KG) is a knowledge base that uses a graph-structured data model or topology to integrate data.
- Knowledge graphs are often used to store interlinked descriptions of entities – objects, events, facts or abstract concepts – while also encoding the semantics underlying the used terminology

1.3 Knowledge Representation & Reasoning

- Knowledge graph

1.3 Knowledge Representation & Reasoning

- Knowledge graph

1.3 Knowledge Representation & Reasoning

Knowledge graph

- Firstly, in 2012, Google introduced their Knowledge Graph to enhance semantic search and improve search quality based on multi-source data on Internet.

Google Knowledge Graph

From Wikipedia, the free encyclopedia
(Redirected from Knowledge Graph)

"Knowledge Graph" redirects here. For the general concept in information science, see Knowledge graph. For other uses, see Knowledge Graph (disambiguation).

The **Google Knowledge Graph** is a knowledge base from which Google serves relevant information in an infobox beside its search results. This allows the user to see the answer in a glance. The data is generated automatically from a variety of sources, covering places, people, businesses, and more. [1][2]

The information covered by Google's Knowledge Graph grew quickly after launch, tripling its size within seven months (covering 570 million entities and 18 billion facts[3]). By mid-2016, Google reported that it held 70 billion facts[4] and answered "roughly one-third" of the 100 billion monthly searches they handled. By May 2020, this had grown to 500 billion facts on 5 billion entities.[5]

There is no official documentation of how the Google Knowledge Graph is implemented.[6] According to Google, its information is retrieved from many sources, including the *CIA World Factbook* and Wikipedia.[7] It is used to answer direct spoken questions in Google Assistant[8][9] and Google Home voice queries.[10] It has been criticized for providing answers without source attribution or citation.[11]

Knowledge Card

1.3 Knowledge Representation & Reasoning

Knowledge graph

- From academic way, we can give a definition as following:

  a knowledge base of semantic network.

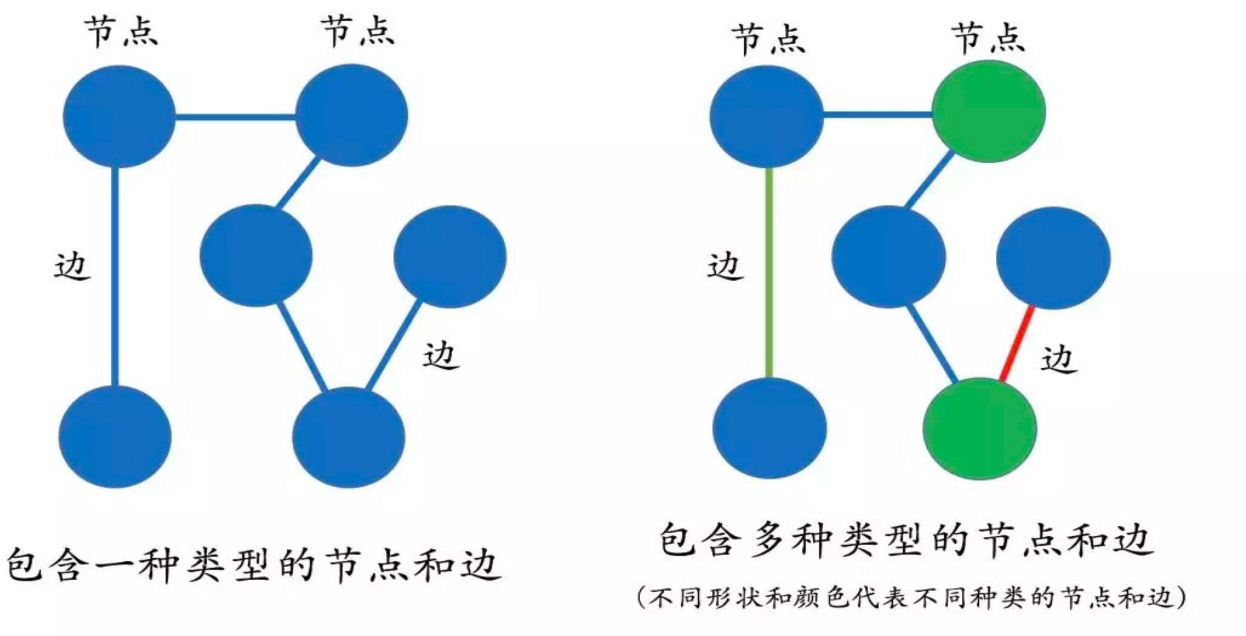
- From practical way, it would be regarded as:

  a multi-relational graph

1.3 Knowledge Representation & Reasoning

Knowledge graph

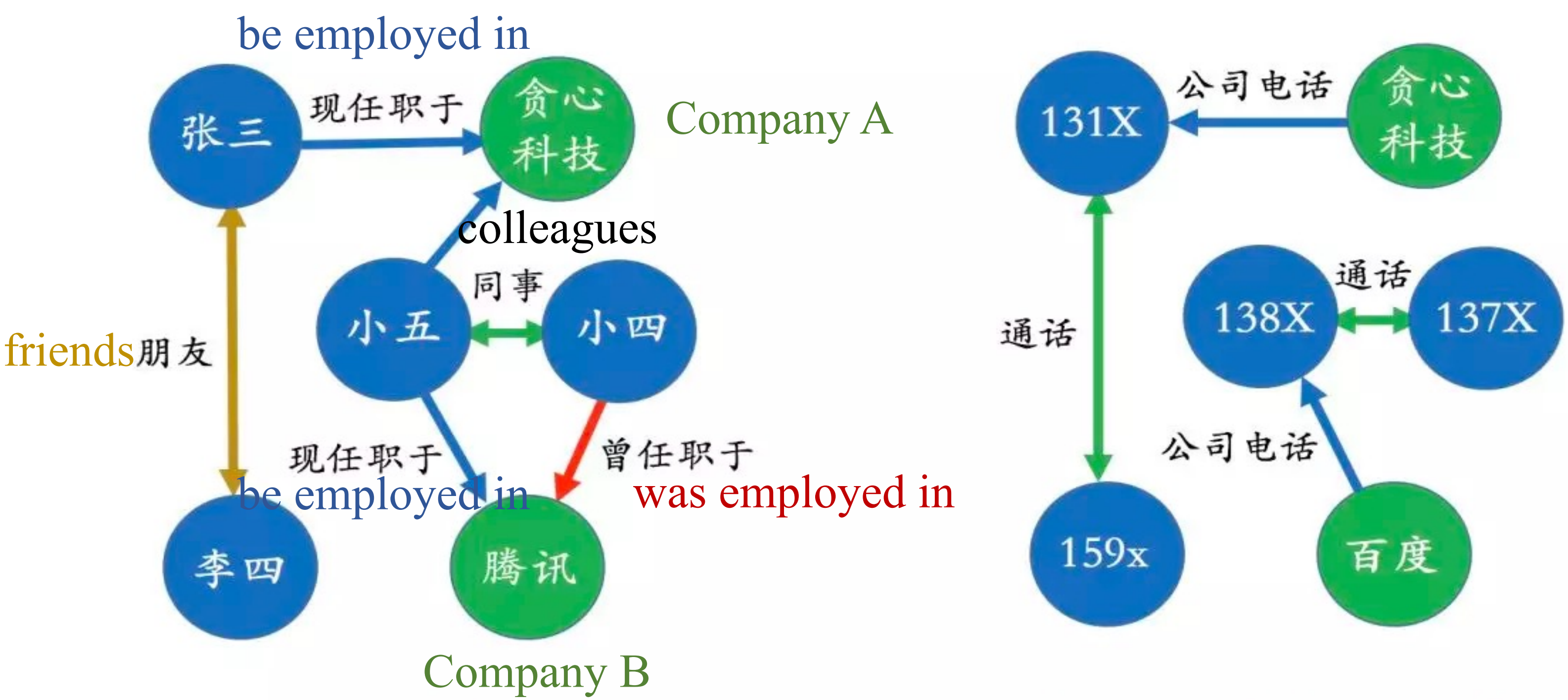
- a multi-relational graph: consist of vertex (节点) and edge (边)
- The vertexes and edges could be different from other vertexes and edges.



1.3 Knowledge Representation & Reasoning

Knowledge graph

- In knowledge graph, we always use “entity” to represent the vertexes while the ‘relation’ is used to describe the edges.



案例：社交网络　　案例：风控知识图谱

1.3 Knowledge Representation & Reasoning

Knowledge graph

- Universal knowledge graph (通用知识图谱)
- Domain knowledge graph (行业知识图谱)

1.3 Knowledge Representation & Reasoning

Knowledge graph

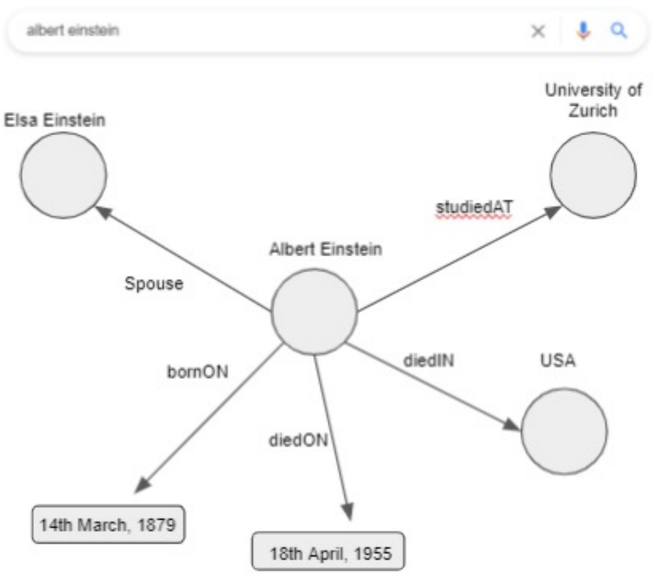
- Universal knowledge graph (通用知识图谱)
  - The knowledge graph proposed by Google is a Universal knowledge graph for the whole domain
  - Internet-oriented search, recommendation, QA

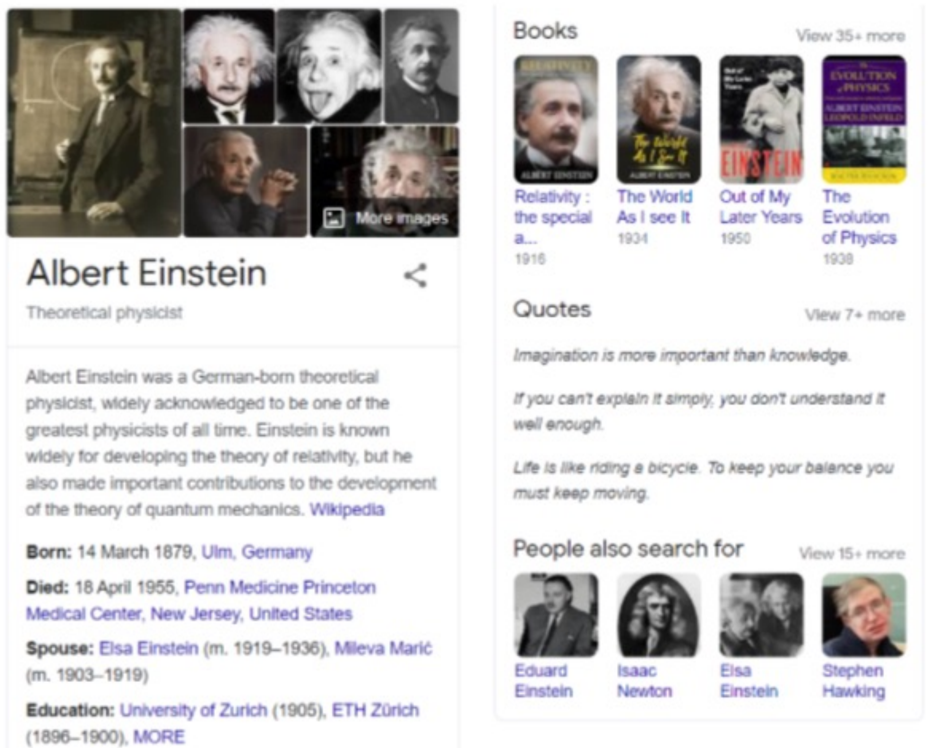
1.3 Knowledge Representation & Reasoning

Knowledge graph

- Universal knowledge graph

Google Knowledge Panel





1.3 Knowledge Representation & Reasoning

Knowledge graph

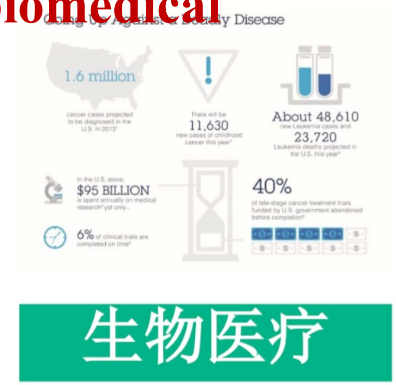
- Domain knowledge graph (行业知识图谱)
  - Domain-specific knowledge graphs
  - The target user needs to consider various levels of personnel in the industry. Different personnel with different operations and business scenarios, so a certain depth and completeness are required.
  - Used to assist various complex analysis applications or decision support.
  - Have strict and rich data patterns

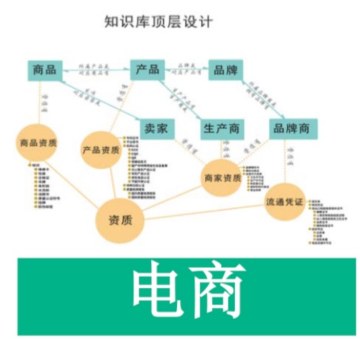
1.3 Knowledge Representation & Reasoning

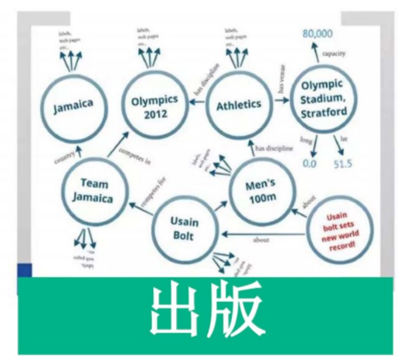
Knowledge graph

- Domain knowledge graph (行业知识图谱)

Finance **biomedical** **library and information** **e-commerce**





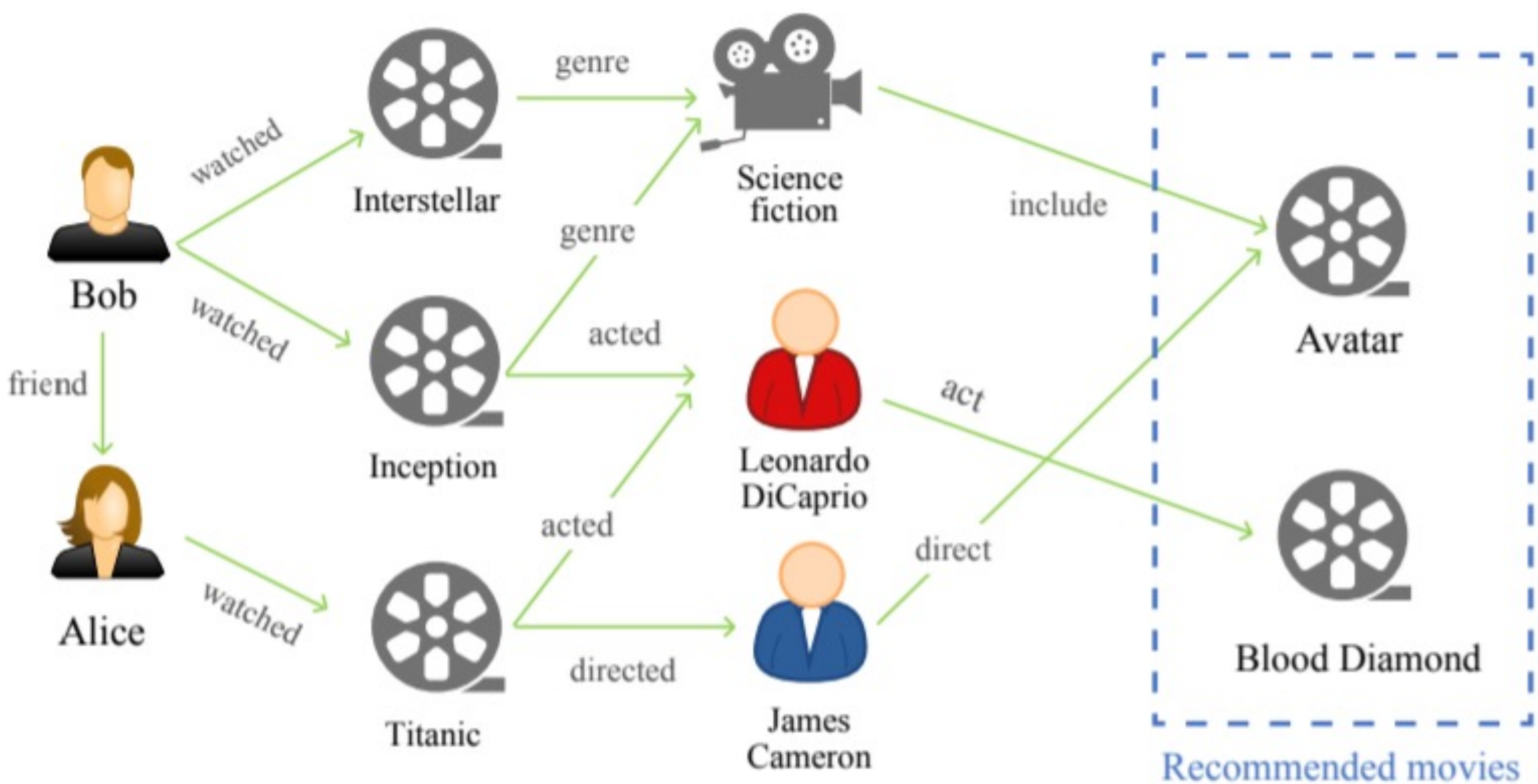


agriculture **government** **Telecommunications** **publish**

1.3 Knowledge Representation & Reasoning

Knowledge graph ---- Example

A sample knowledge graph for movie recommendation task



1.3 Knowledge Representation & Reasoning

Knowledge graph ---- Example

•we can see one KG (movie KG) that not only contains user-item connections (here person-movies) but also user-user interactions and item attributes.

•"Avatar" could be recommended to,

— Bob: as it belongs to the Sci-fi movie same as Interstellar and Inception (which is already watched by Bob)

— Alice: as it is directed by James Cameron (Titanic)

•"Blood Diamond" could be recommended to,

— Bob: as DiCaprio acted in Inception as well

•This simple thought exercise should showcase how a lot of real-world interactions can be easily represented in form of facts using KG. And then we can leverage KG-based algorithms for a downstream use case like generating recommendations.

Summary

1. Proposition : A proposition is a declarative sentence that is either true or false.
2. Logical connectives: AND, OR, IMPALICATION, NOT, BICONDITIONAL
3. Truth Table
4. Tautology, Contradiction, Contingency
5. Logically equivalent
6. Predicate Logic
7. Quantification, the universal quantifier & existential quantifier
8. Mixing quantifier
9. Production-rule system
10. Frame-based system
11. State space system
12. Knowledge graph