Artificial Intelligence

Artificial Intelligence and Intelligent Agents; Problem Solving

1131AI02
MBA, IM, NTPU (M5276) (Fall 2024)
Tue 2, 3, 4 (9:10-12:00) (B3F17)

https://meet.google.com/paj-zhhj-mya

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Professor

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https://web.ntpu.edu.tw/~myday

2024-09-24

Syllabus

Week	Date	Subject/Topics
1	2024/09/10	Introduction to Artificial Intelligence
2	2024/09/17	Mid-Autumn Festival (Day off)
3	2024/09/24	Artificial Intelligence and Intelligent Agents; Problem Solving
4	2024/10/01	Knowledge, Reasoning and Knowledge Representation; Uncertain Knowledge and Reasoning
5	2024/10/08	Case Study on Artificial Intelligence I
6	2024/10/15	Machine Learning: Supervised and Unsupervised Learning

Syllabus

Week	Date	Subject/Topics
7	2024/10/22	The Theory of Learning and Ensemble Learning
8	2024/10/29	Midterm Project Report
9	2024/11/05	Self-Learning
10	2024/11/12	Deep Learning, Reinforcement Learning
11	2024/11/19	Case Study on Artificial Intelligence II
12	2024/11/26	Deep Learning for Natural Language Processing

Syllabus

Week	Date	Subject/Topics
13	2024/12/03	Computer Vision and Robotics
14	2024/12/10	Generative AI, Philosophy and Ethics of AI and the Future of AI
15	2024/12/17	Final Project Report I
16	2024/12/24	Final Project Report II

Artificial Intelligence
Intelligent Agents
Problem Solving

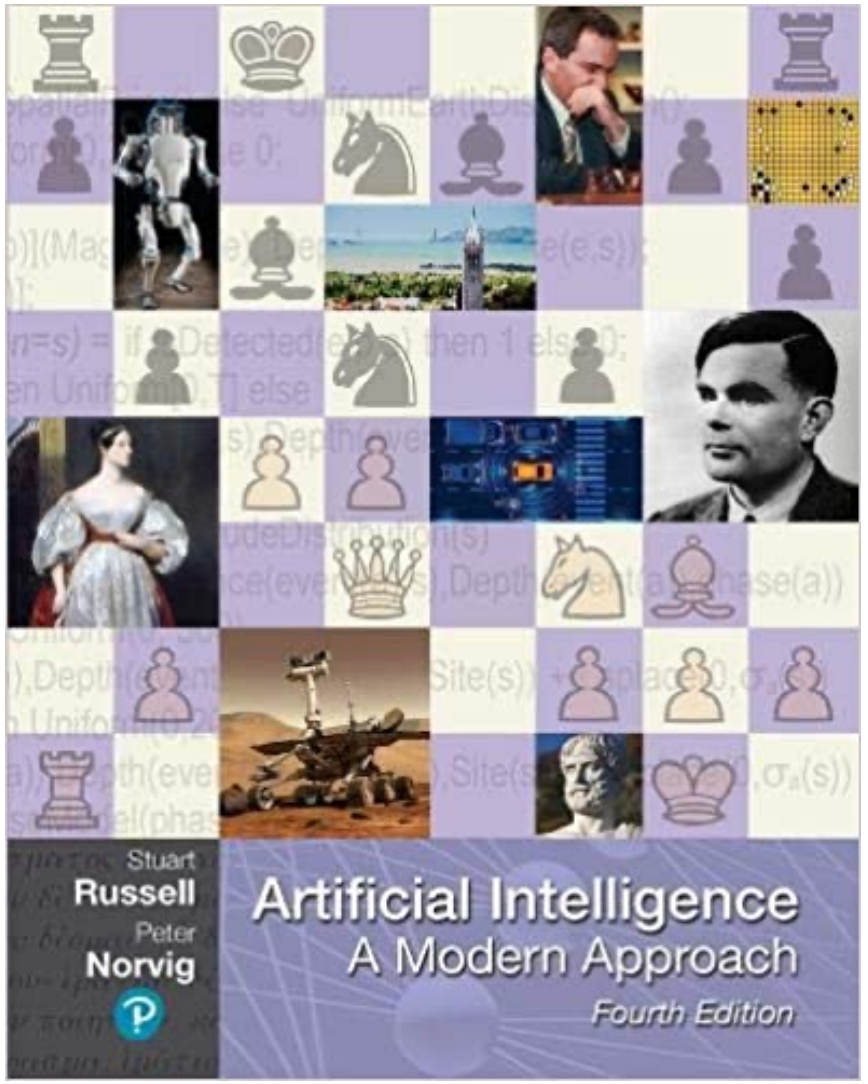
Outline

- **Artificial Intelligence**
- **Intelligent Agents**
- **Problem Solving**

Stuart Russell and Peter Norvig (2020),

Artificial Intelligence: A Modern Approach,

4th Edition, Pearson



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

https://www.amazon.com/Artificial-Intelligence-A-Modern-Approach/dp/0134610997/

Artificial Intelligence: A Modern Approach

1. **Artificial Intelligence**
2. **Problem Solving**
3. **Knowledge and Reasoning**
4. **Uncertain Knowledge and Reasoning**
5. **Machine Learning**
6. **Communicating, Perceiving, and Acting**
7. **Philosophy and Ethics of AI**

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence: Intelligent Agents

Artificial Intelligence:
2. Problem Solving

- Solving Problems by Searching
- Search in Complex Environments
- Adversarial Search and Games
- Constraint Satisfaction Problems

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence:
3. Knowledge and Reasoning

- Logical Agents
- First-Order Logic
- Inference in First-Order Logic
- Knowledge Representation
- Automated Planning

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence:

4. Uncertain Knowledge and Reasoning

- Quantifying Uncertainty
- Probabilistic Reasoning
- Probabilistic Reasoning over Time
- Probabilistic Programming
- Making Simple Decisions
- Making Complex Decisions
- Multiagent Decision Making

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence:
5. Machine Learning

- Learning from Examples
- Learning Probabilistic Models
- Deep Learning
- Reinforcement Learning

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence:

6. Communicating, Perceiving, and Acting

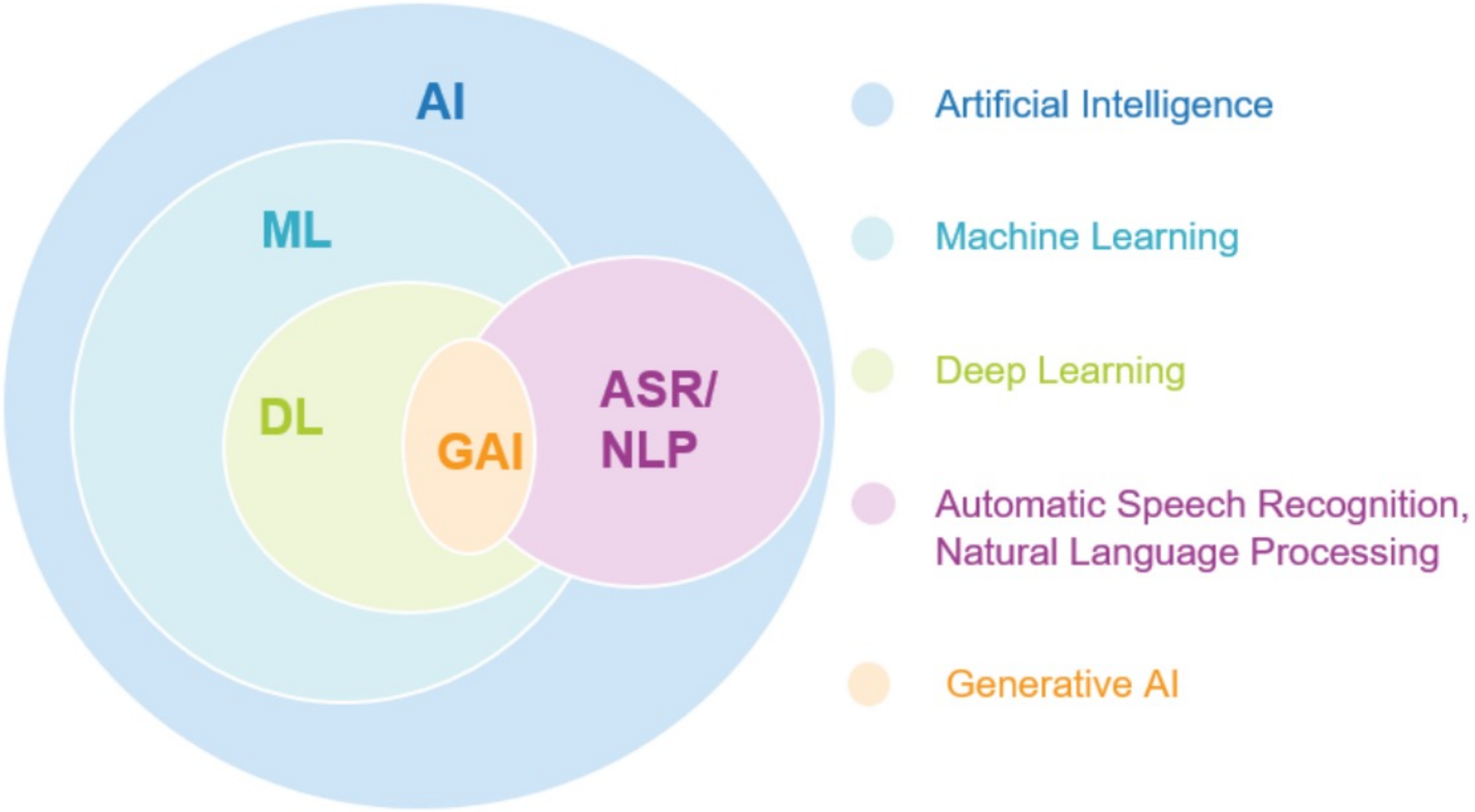
- **Natural Language Processing**
- **Deep Learning for Natural Language Processing**
- **Computer Vision**
- **Robotics**

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence:
Philosophy and Ethics of AI
The Future of AI

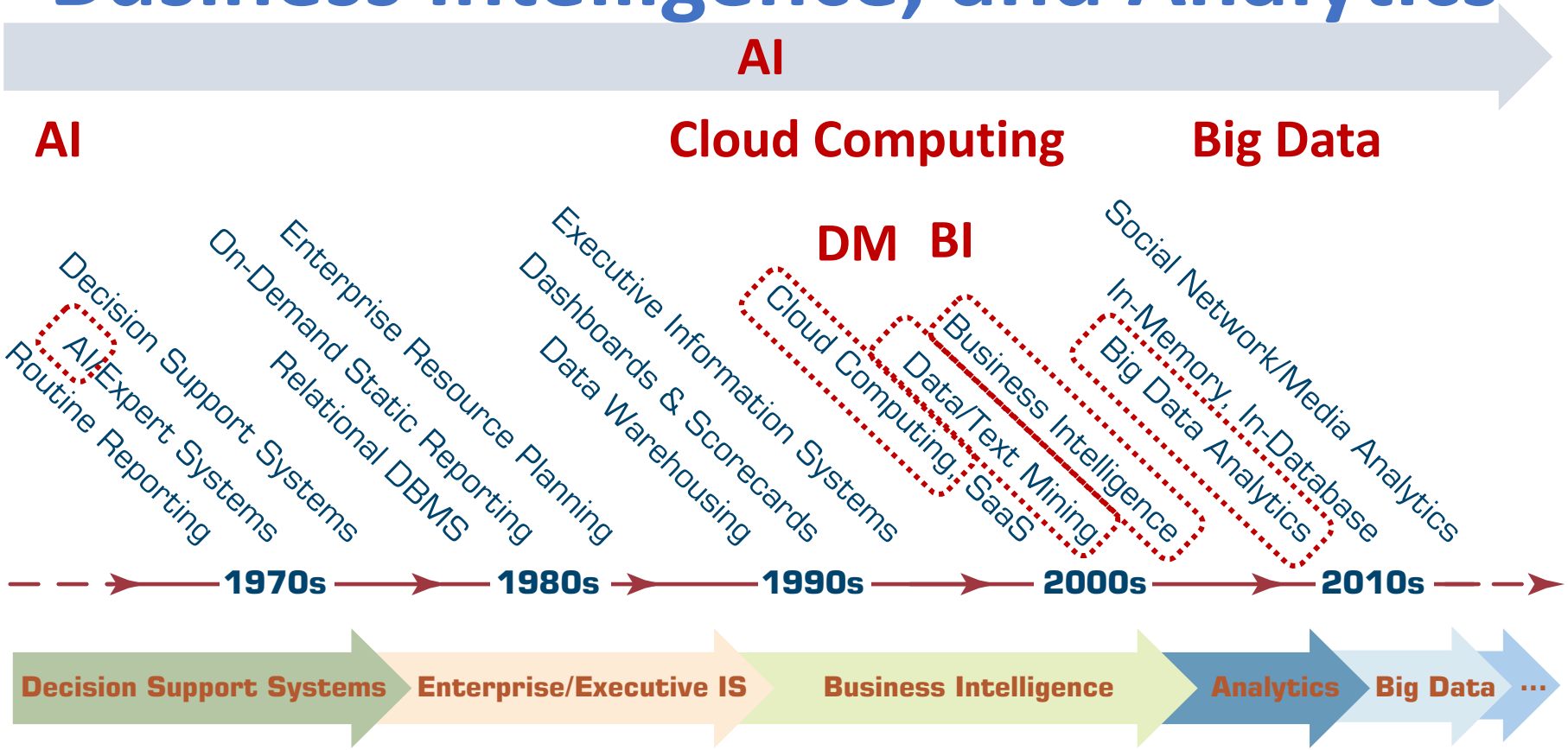
Artificial Intelligence (AI)

AI, ML, DL, Generative AI



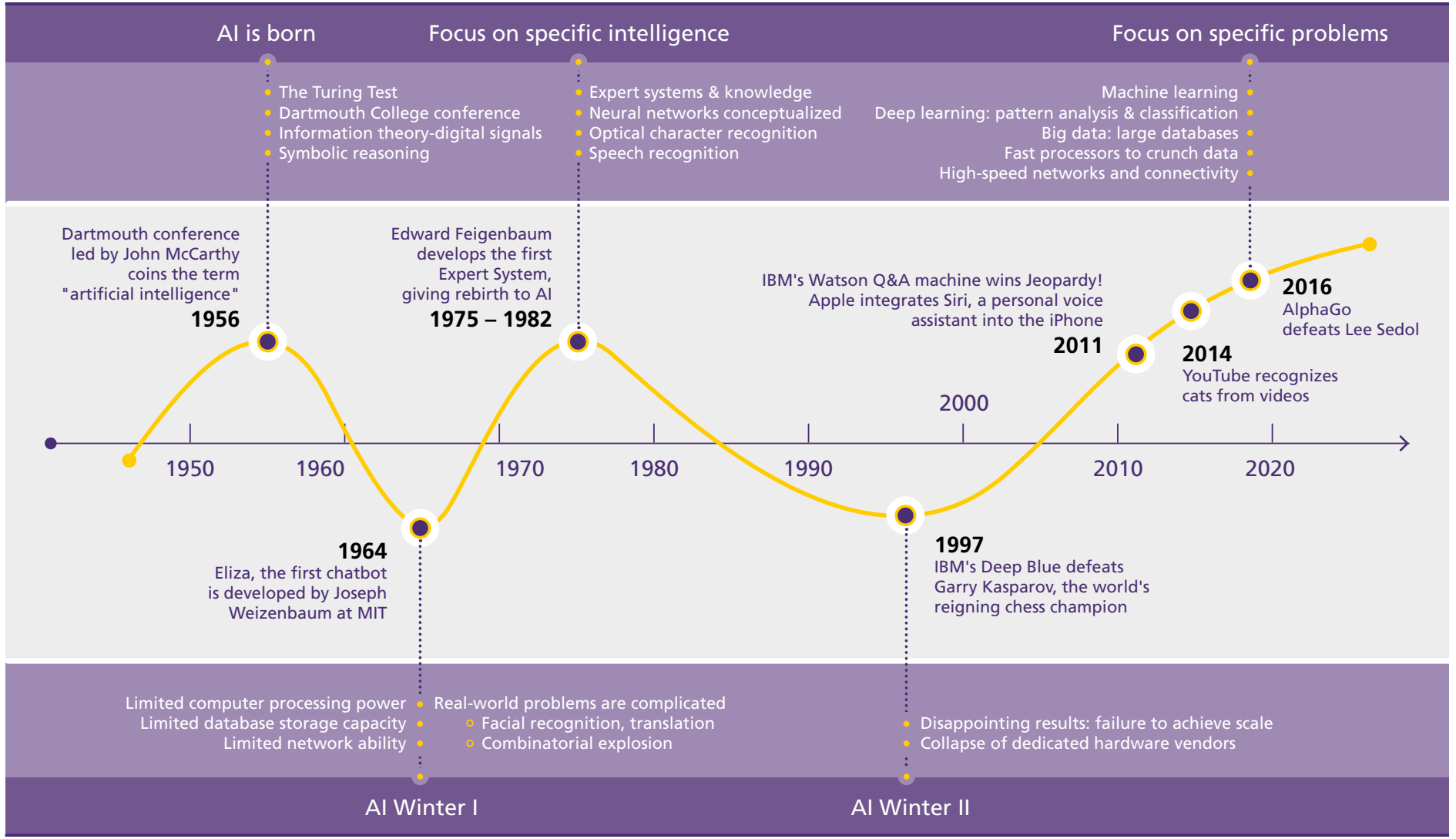
Source: Jeong, Cheonsu. "A Study on the Implementation of Generative AI Services Using an Enterprise Data-Based LLM Application Architecture." arXiv preprint arXiv:2309.01105 (2023).

AI, Big Data, Cloud Computing
Evolution of Decision Support, Business Intelligence, and Analytics



Source: Ramesh Sharda, Dursun Delen, and Efraim Turban (2017),
Business Intelligence, Analytics, and Data Science: A Managerial Perspective, 4th Edition, Pearson

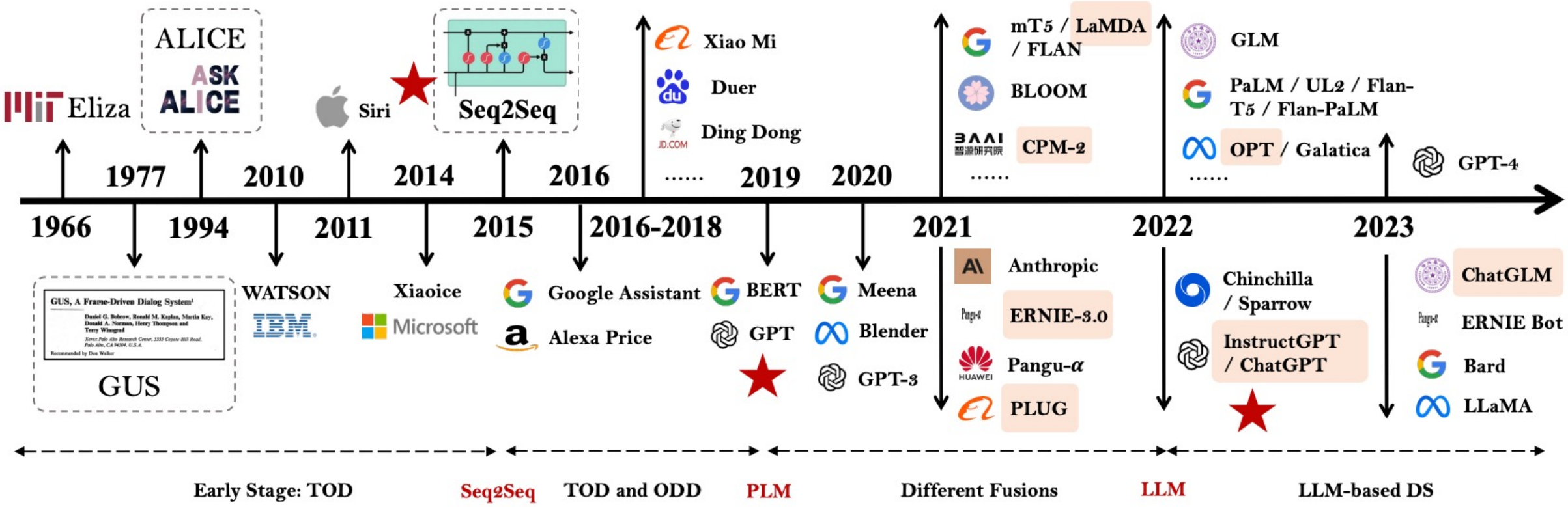
The Rise of AI



Source: DHL (2018), Artificial Intelligence in Logistics, http://www.globalhha.com/doclib/data/upload/doc_con/5e50c53c5bf67.pdf/

The Development of LM-based Dialogue Systems

1) Early Stage (1966 - 2015)
2) The Independent Development of TOD and ODD (2015 - 2019)
3) Fusions of Dialogue Systems (2019 - 2022)
4) LLM-based DS (2022 - Now)



Task-oriented DS (TOD), Open-domain DS (ODD)

Source: Wang, Hongru, Lingzhi Wang, Yiming Du, Liang Chen, Jingyan Zhou, Yufei Wang, and Kam-Fai Wong. "A Survey of the Evolution of Language Model-Based Dialogue Systems." arXiv preprint arXiv:2311.16789 (2023).

Definition of Artificial Intelligence (A.I.)

Artificial Intelligence

"… the science and engineering of making intelligent machines"

(John McCarthy, 1955)

Source: https://digitalintelligencetoday.com/artificial-intelligence-defined-useful-list-of-popular-definitions-from-business-and-science/

Artificial Intelligence

“… technology that thinks and acts like humans”

Source: https://digitalintelligencetoday.com/artificial-intelligence-defined-useful-list-of-popular-definitions-from-business-and-science/

Artificial Intelligence

"… intelligence exhibited by machines or software"

Source: https://digitalintelligencetoday.com/artificial-intelligence-defined-useful-list-of-popular-definitions-from-business-and-science/

4 Approaches of AI

Thinking Humanly	**Thinking Rationally**
Acting Humanly	**Acting Rationally**

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

4 Approaches of AI

2. **Thinking Humanly:** **The Cognitive Modeling Approach**	**3.** **Thinking Rationally:** **The "Laws of Thought" Approach**
1. **Acting Humanly:** **The Turing Test Approach (1950)**	**4.** **Acting Rationally:** **The Rational Agent Approach**

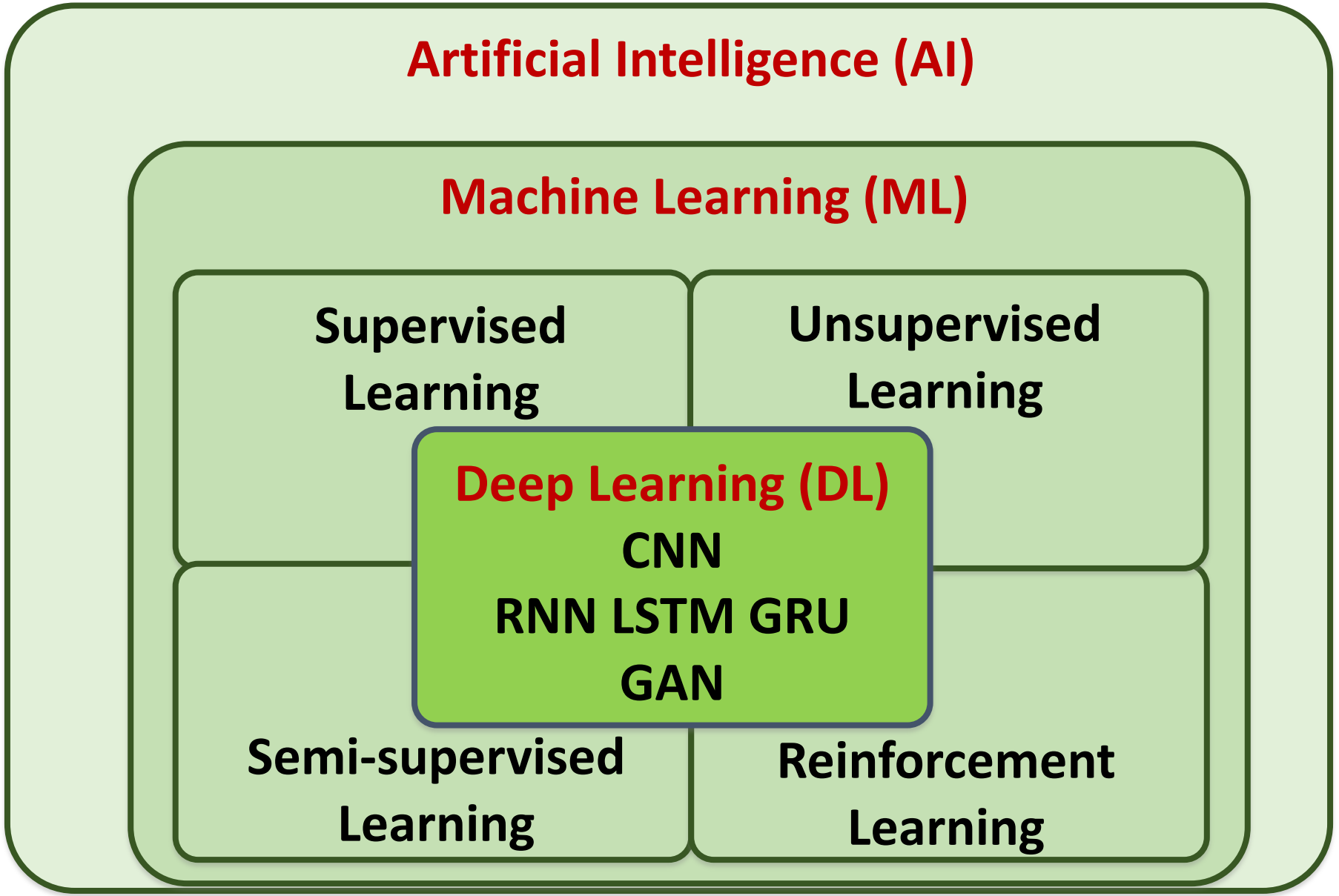
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

AI Acting Humanly:
The Turing Test Approach
(Alan Turing, 1950)

- Knowledge Representation
- Automated Reasoning
- Machine Learning (ML)
  - Deep Learning (DL)
- Computer Vision (Image, Video)
- Natural Language Processing (NLP)
- Robotics

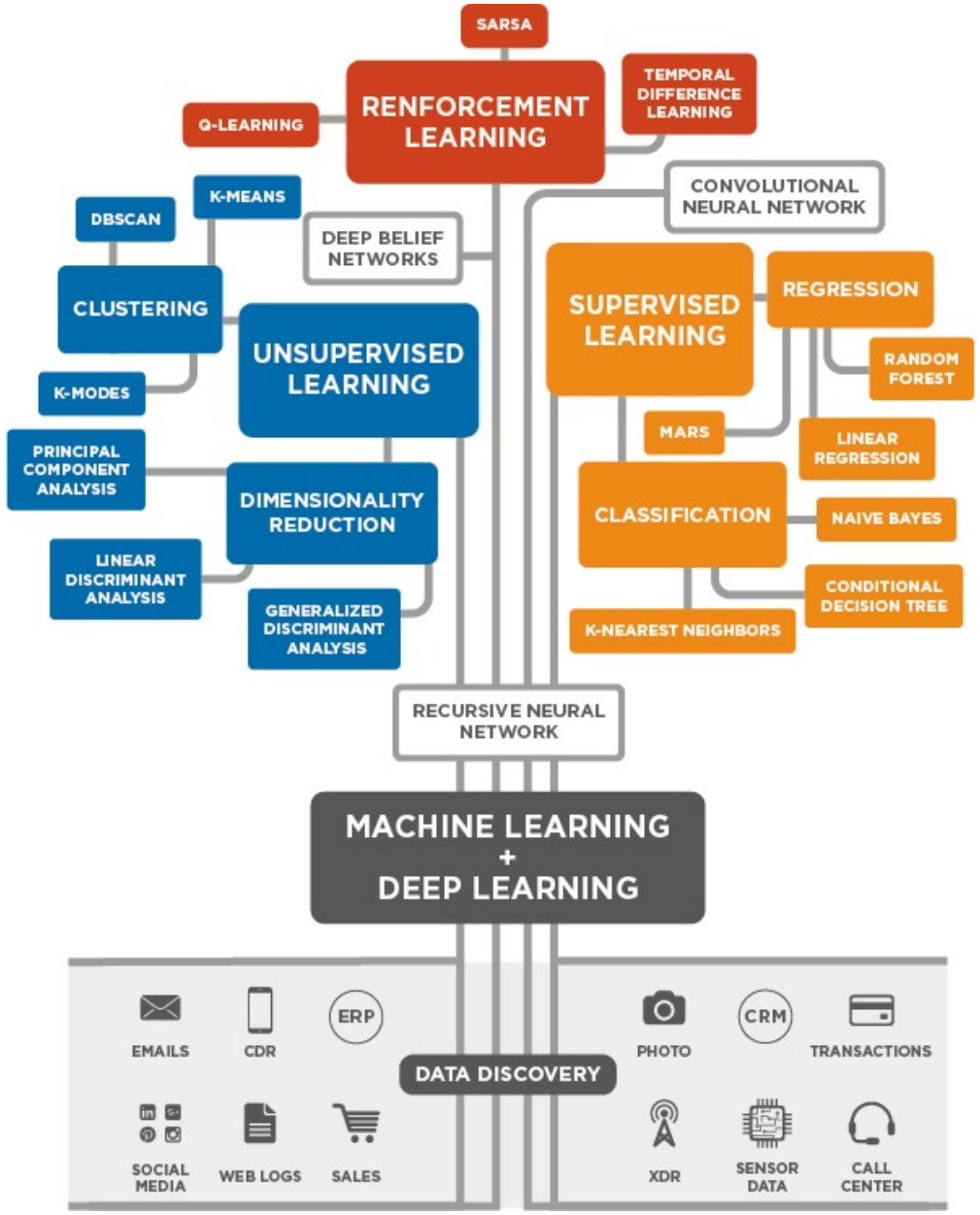
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

AI, ML, DL



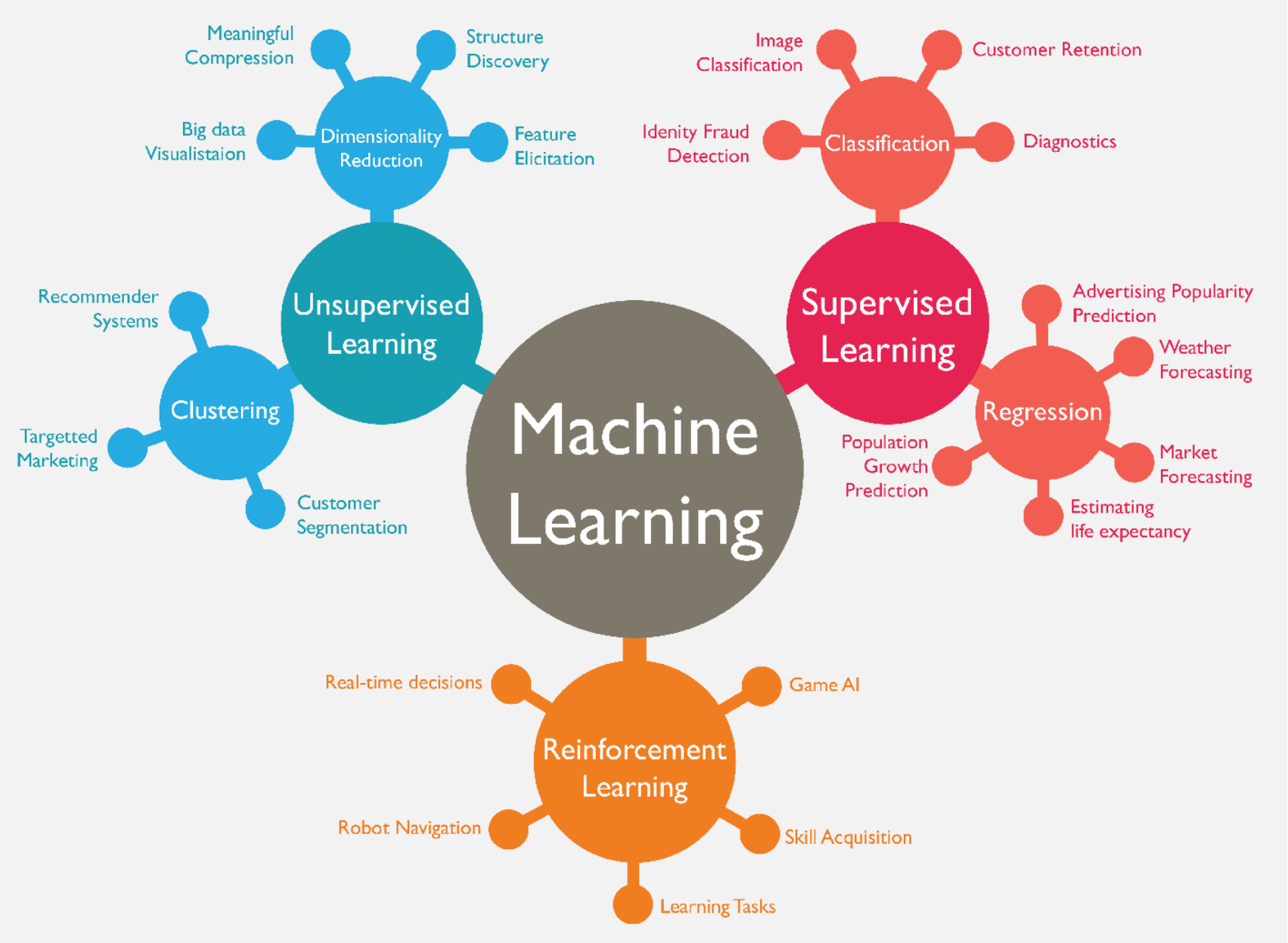
Source: https://leonardoaraujosantos.gitbooks.io/artificial-inteligence/content/deep_learning.html

3 Machine Learning Algorithms



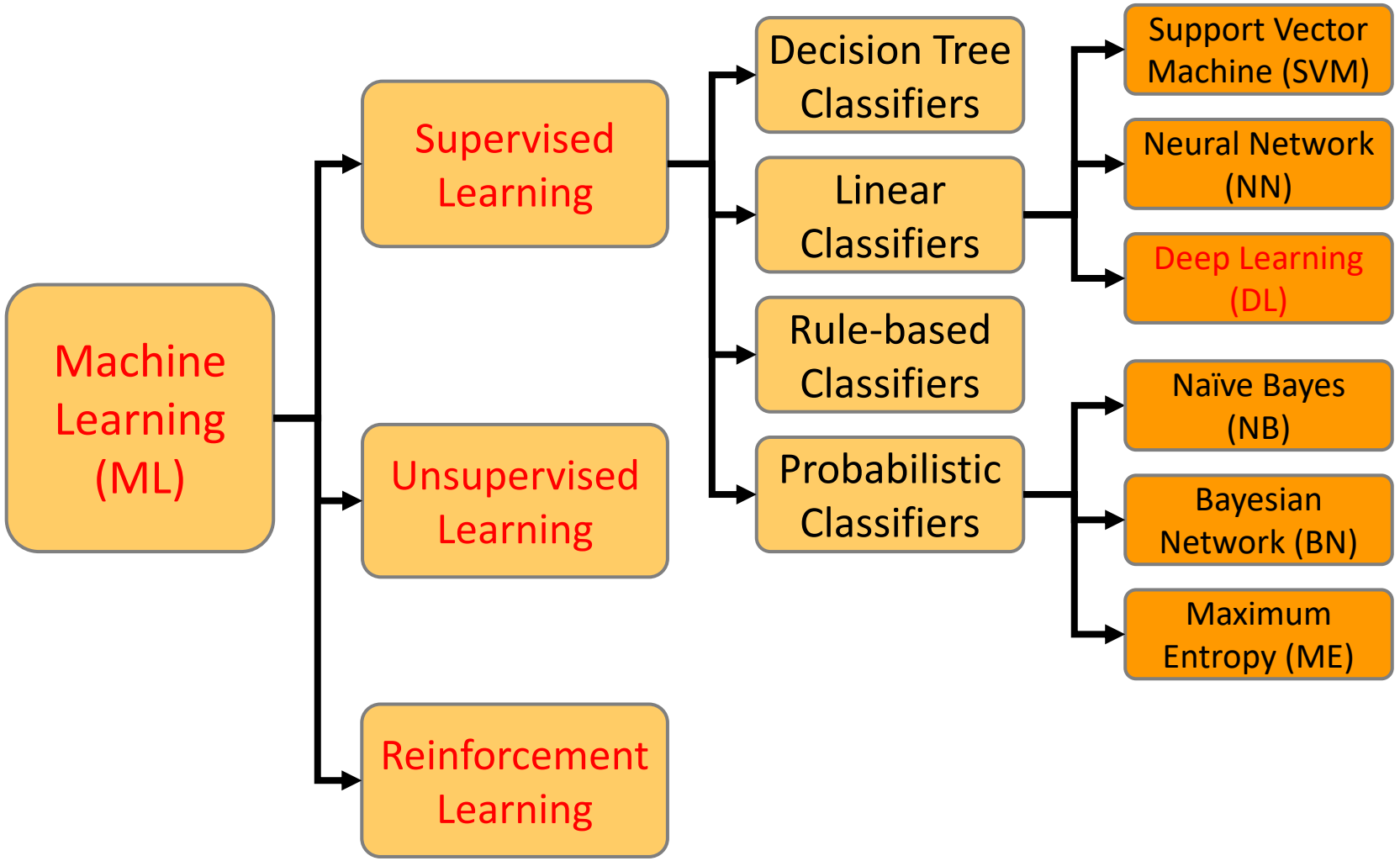
Source: Enrico Galimberti, http://blogs.teradata.com/data-points/tree-machine-learning-algorithms/

Machine Learning (ML)



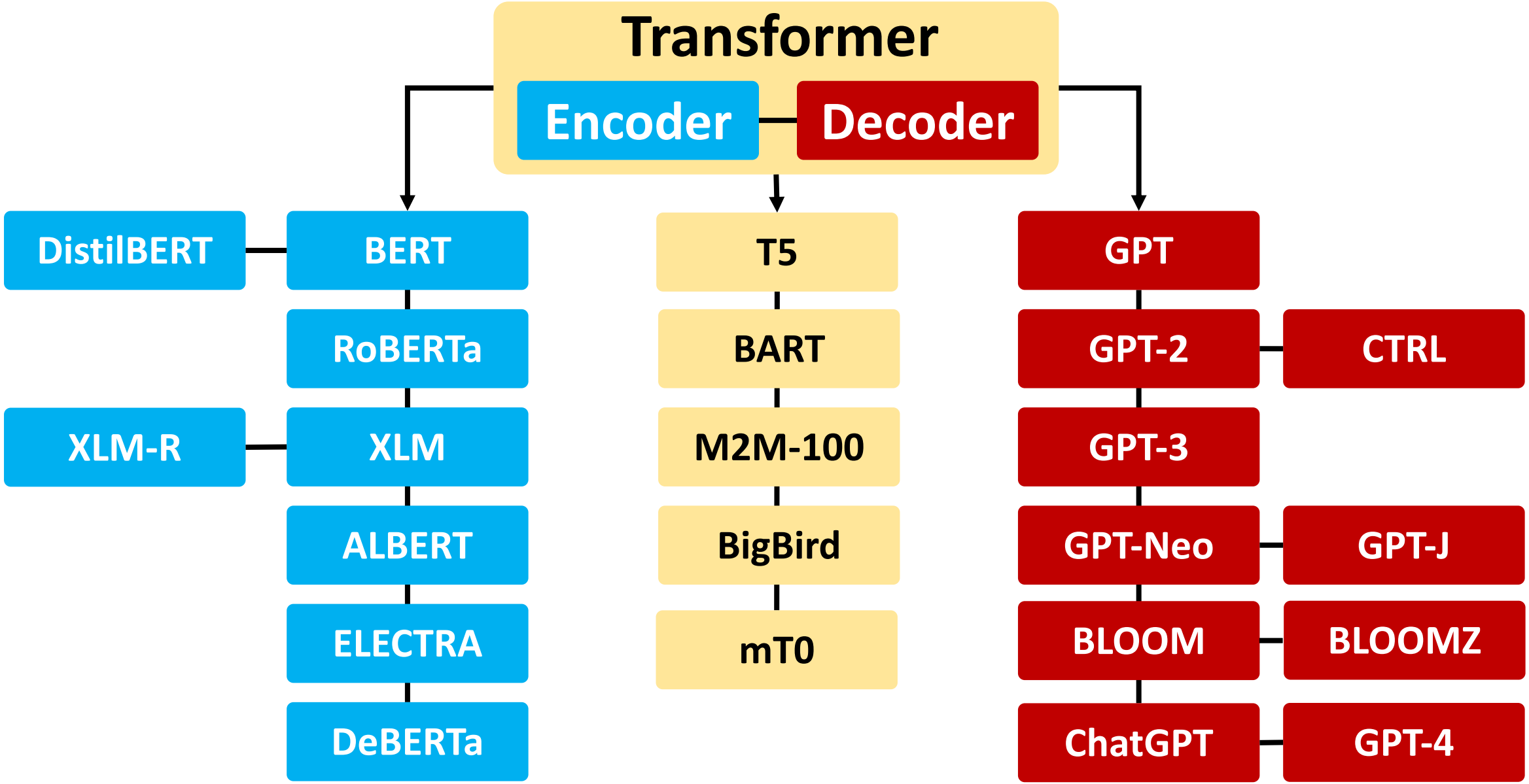
Source: https://www.mactores.com/services/aws-big-data-machine-learning-cognitive-services/

Machine Learning (ML) / Deep Learning (DL)



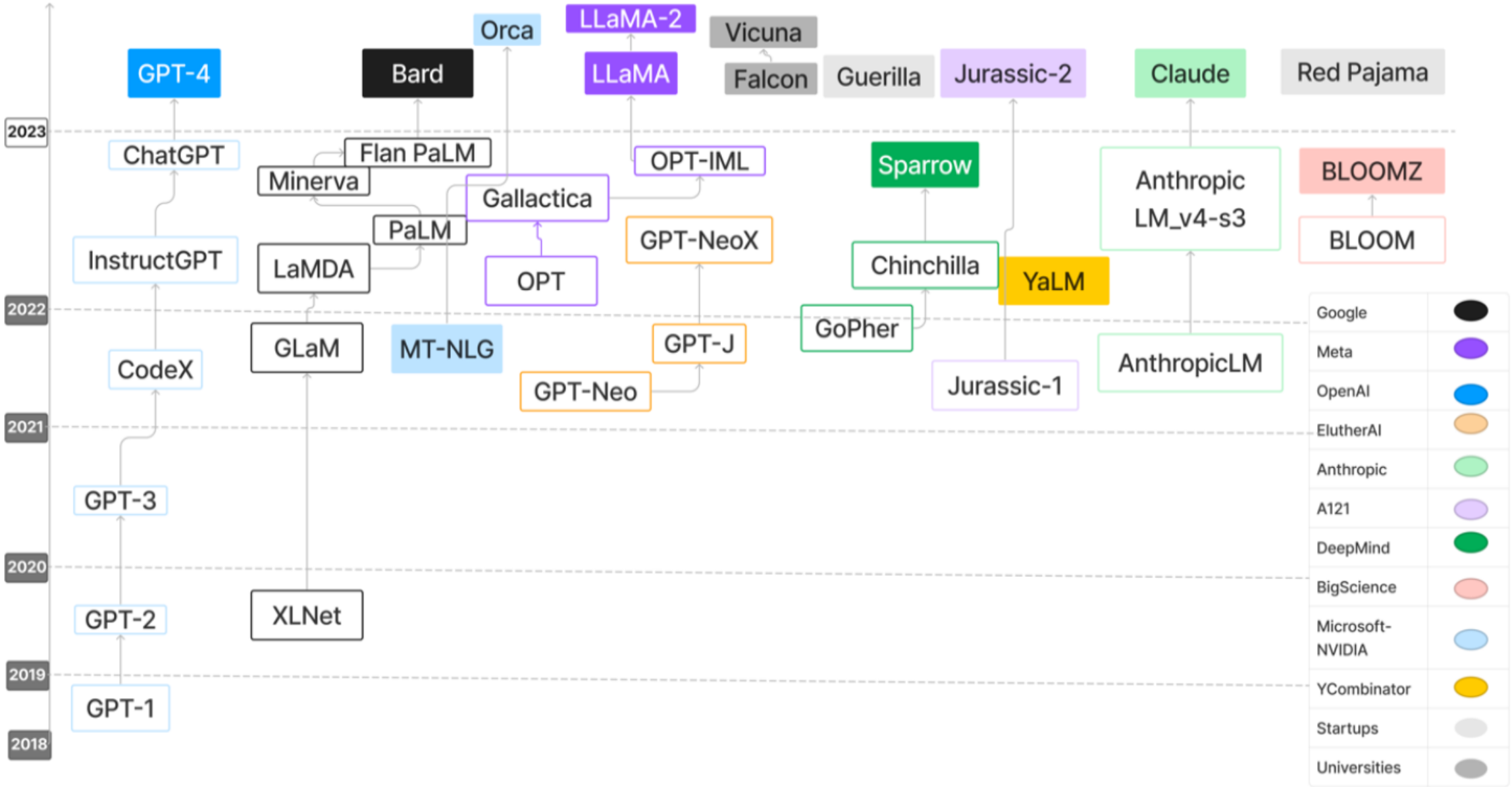
Source: Jesus Serrano-Guerrero, Jose A. Olivas, Francisco P. Romero, and Enrique Herrera-Viedma (2015), "Sentiment analysis: A review and comparative analysis of web services," Information Sciences, 311, pp. 18-38.

Transformer Models



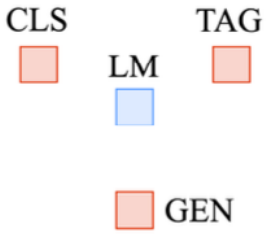
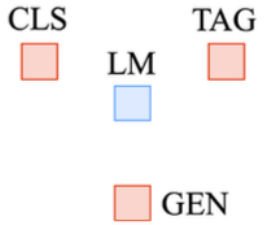
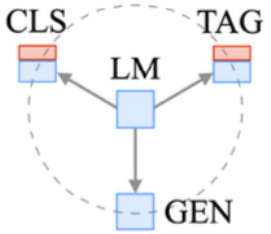
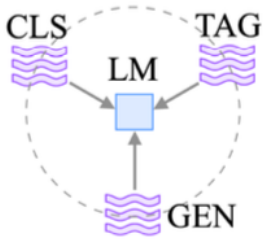
Source: Lewis Tunstall, Leandro von Werra, and Thomas Wolf (2022), Natural Language Processing with Transformers: Building Language Applications with Hugging Face, O'Reilly Media.

Large Language Models (LLMs)



Source: Hadi, Muhammad Usman, Rizwan Qureshi, Abbas Shah, Muhammad Irfan, Anas Zafar, Muhammad Bilal Shaikh, Naveed Akhtar, Jia Wu, and Seyedali Mirjalili. "Large language models: a comprehensive survey of its applications, challenges, limitations, and future prospects." Authorea Preprints (2023).

Four Paradigms in NLP (LM)

Paradigm	Engineering	Task Relation
a. Fully Supervised Learning (Non-Neural Network)	Feature (e.g. word identity, part-of-speech, sentence length)	
b. Fully Supervised Learning (Neural Network)	Architecture (e.g. convolutional, recurrent, self-attentional)	
Transfer Learning: Pre-training, Fine-Tuning (FT) c. Pre-train, Fine-tune	Objective (e.g. masked language modeling, next sentence prediction)	
GAI: Pre-train, Prompt, and Predict (Prompting) d. Pre-train, Prompt, Predict	Prompt (e.g. cloze, prefix)	

Source: Pengfei Liu, Weizhe Yuan, Jinlan Fu, Zhengbao Jiang, Hiroaki Hayashi, and Graham Neubig. (2023) "Pre-train, prompt, and predict: A systematic survey of prompting methods in natural language processing." ACM Computing Surveys 55, no. 9 (2023): 1-35.

Generative AI

Text, Image, Video, Audio Applications

Comparison of Generative AI and Traditional AI

Feature	Generative AI	Traditional AI
Output type	New content	Classification/Prediction
Creativity	High	Low
Interactivity	Usually more natural	Limited

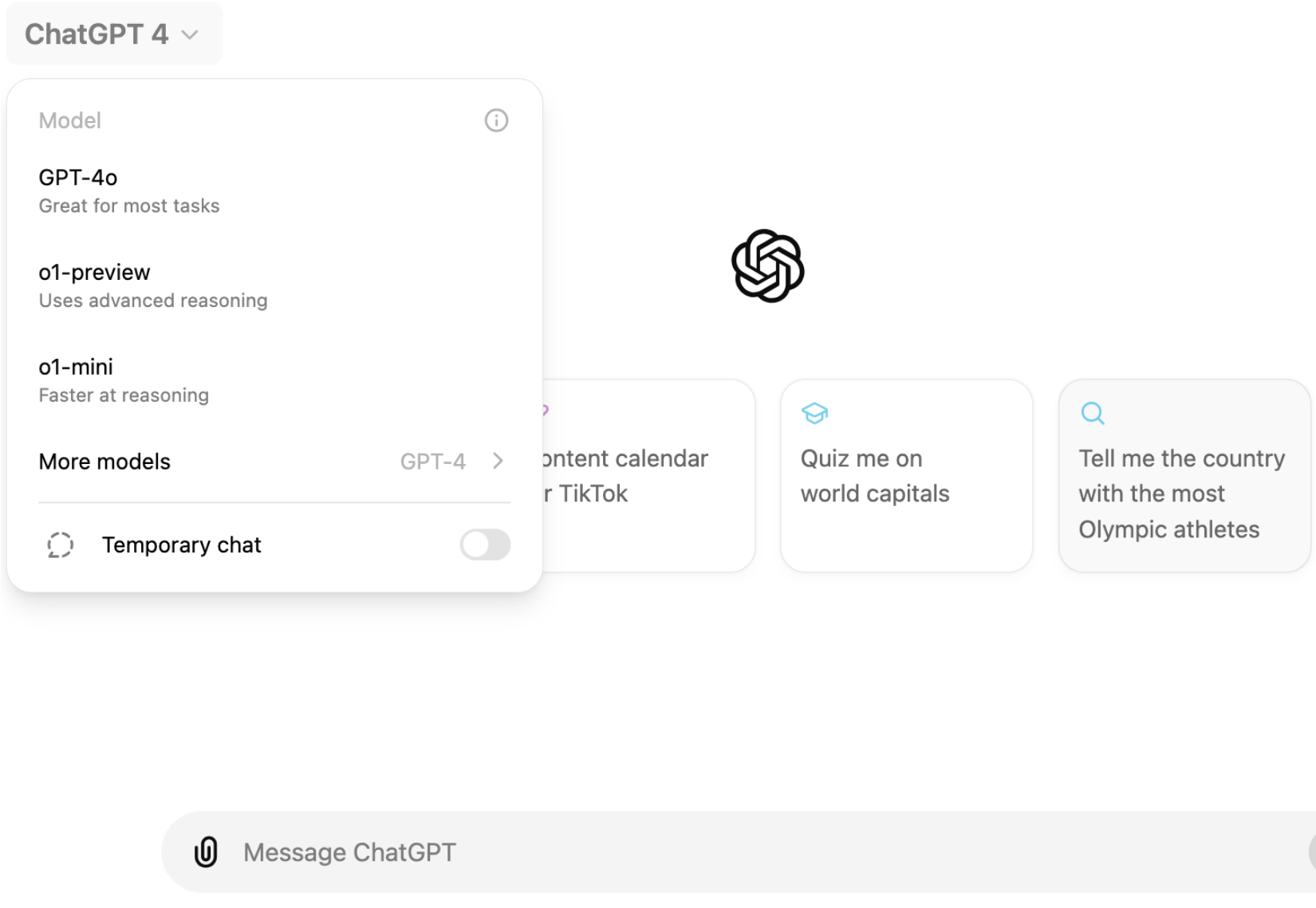
Generative AI

- **Generative AI: The Art of Creation**
- **Definition: AI systems capable of creating new content**
- **Characteristics: Creativity, interactivity**

Popular Generative AI

- OpenAI ChatGPT (GPT-4o, GPT-4)
- Claude.ai (Claude 3.5)
- Google Gemini
- Chat.LMSys.org
- Perplexity.ai
- ChatPDF
- Stable Diffusion
- Video: D-ID, Synthesia
- Audio: Speechify

OpenAI ChatGPT (GPT-4o, GPT-4)



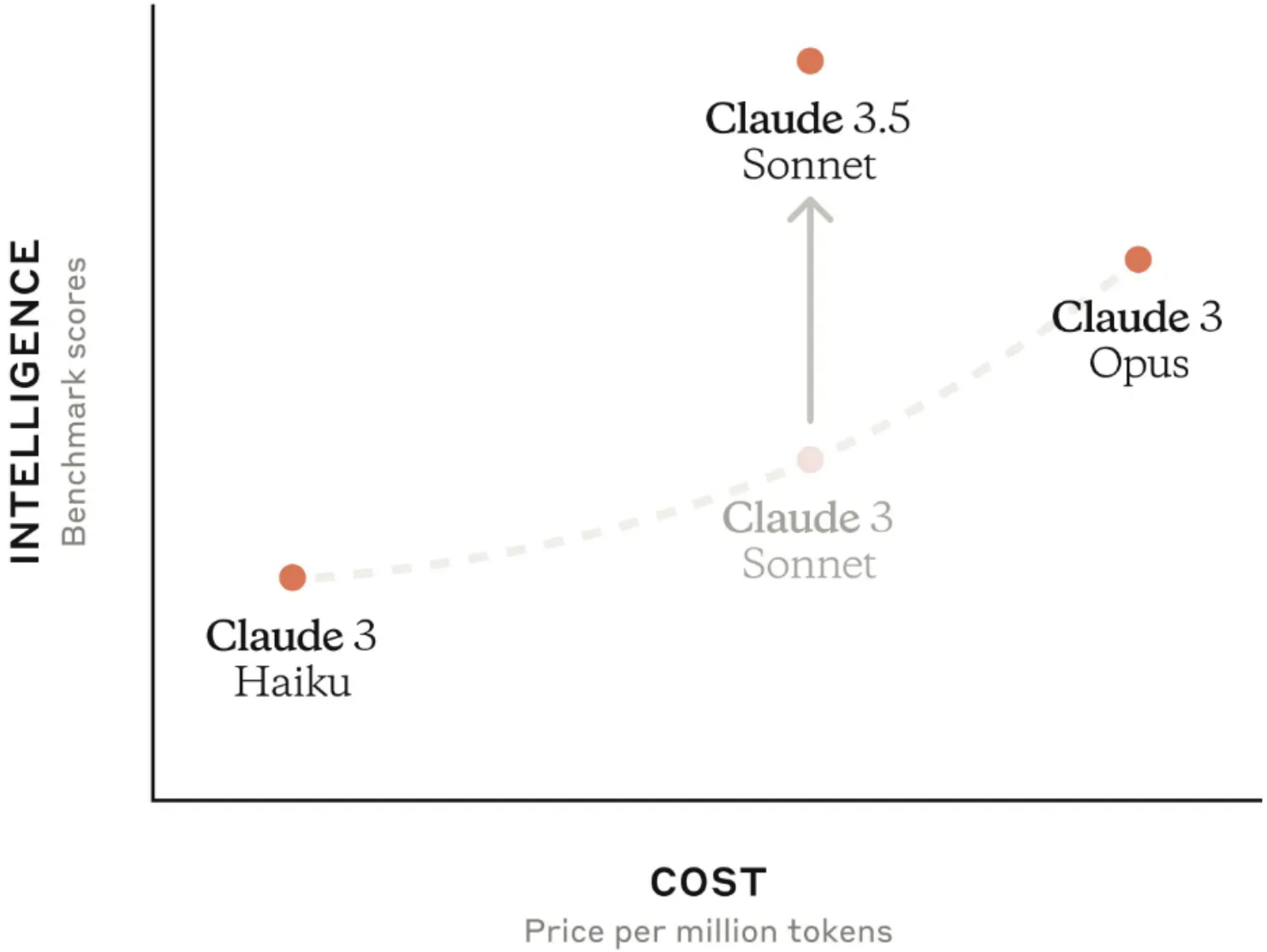
https://chatgpt.com/

OpenAI ChatGPT (GPT-4) DALL·E 3

Vector graphic of a flowchart depicting the integration of generative AI in the education process, from content creation to virtual experiments, personalized learning, and innovative learning.

https://chat.openai.com/

Claude 3.5 Sonnet



Source: https://www.anthropic.com/news/claude-3-5-sonnet

Claude 3.5, GPT-4o, Gemini 1.5 Pro

	Claude 3.5 Sonnet	Claude 3 Opus	GPT-4o	Gemini 1.5 Pro	Llama-400b (early snapshot)
Graduate level reasoning *GPQA, Diamond*	59.4%* 0-shot CoT	50.4% 0-shot CoT	53.6% 0-shot CoT	—	—
Undergraduate level knowledge *MMLU*	88.7%** 5-shot 88.3% 0-shot CoT	86.8% 5-shot 85.7% 0-shot CoT	— 88.7% 0-shot CoT	85.9% 5-shot —	86.1% 5-shot —
Code *HumanEval*	92.0% 0-shot	84.9% 0-shot	90.2% 0-shot	84.1% 0-shot	84.1% 0-shot
Multilingual math *MGSM*	91.6% 0-shot CoT	90.7% 0-shot CoT	90.5% 0-shot CoT	87.5% 8-shot	—
Reasoning over text *DROP, F1 score*	87.1 3-shot	83.1 3-shot	83.4 3-shot	74.9 Variable shots	83.5 3-shot Pre-trained model
Mixed evaluations *BIG-Bench-Hard*	93.1% 3-shot CoT	86.8% 3-shot CoT	—	89.2% 3-shot CoT	85.3% 3-shot CoT Pre-trained model
Math problem-solving *MATH*	71.1% 0-shot CoT	60.1% 0-shot CoT	76.6% 0-shot CoT	67.7% 4-shot	57.8% 4-shot CoT
Grade school math *GSM8K*	96.4% 0-shot CoT	95.0% 0-shot CoT	—	90.8% 11-shot	94.1% 8-shot CoT

* Claude 3.5 Sonnet scores 67.2% on 5-shot CoT GPQA with maj@32
** Claude 3.5 Sonnet scores 90.4% on MMLU with 5-shot CoT prompting

Source: https://www.anthropic.com/news/claude-3-5-sonnet

Claude 3.5 Sonnet State-of-the-art vision

	Claude 3.5 Sonnet	Claude 3 Opus	GPT-4o	Gemini 1.5 Pro
Visual math reasoning *MathVista (testmini)*	**67.7%** 0-shot CoT	**50.5%** 0-shot CoT	**63.8%** 0-shot CoT	**63.9%** 0-shot CoT
Science diagrams *AI2D, test*	**94.7%** 0-shot	**88.1%** 0-shot	**94.2%** 0-shot	**94.4%** 0-shot
Visual question answering *MMMU (val)*	**68.3%** 0-shot CoT	**59.4%** 0-shot CoT	**69.1%** 0-shot CoT	**62.2%** 0-shot CoT
Chart Q&A *Relaxed accuracy (test)*	**90.8%** 0-shot CoT	**80.8%** 0-shot CoT	**85.7%** 0-shot CoT	**87.2%** 0-shot CoT
Document visual Q&A *ANLS score, test*	**95.2%** 0-shot	**89.3%** 0-shot	**92.8%** 0-shot	**93.1%** 0-shot

Source: https://www.anthropic.com/news/claude-3-5-sonnet

Google Gemini

Largest and most capable AI model
Making AI more helpful for everyone

Source: https://blog.google/technology/ai/google-gemini-ai

LMSYS Chatbot Arena Leaderboard

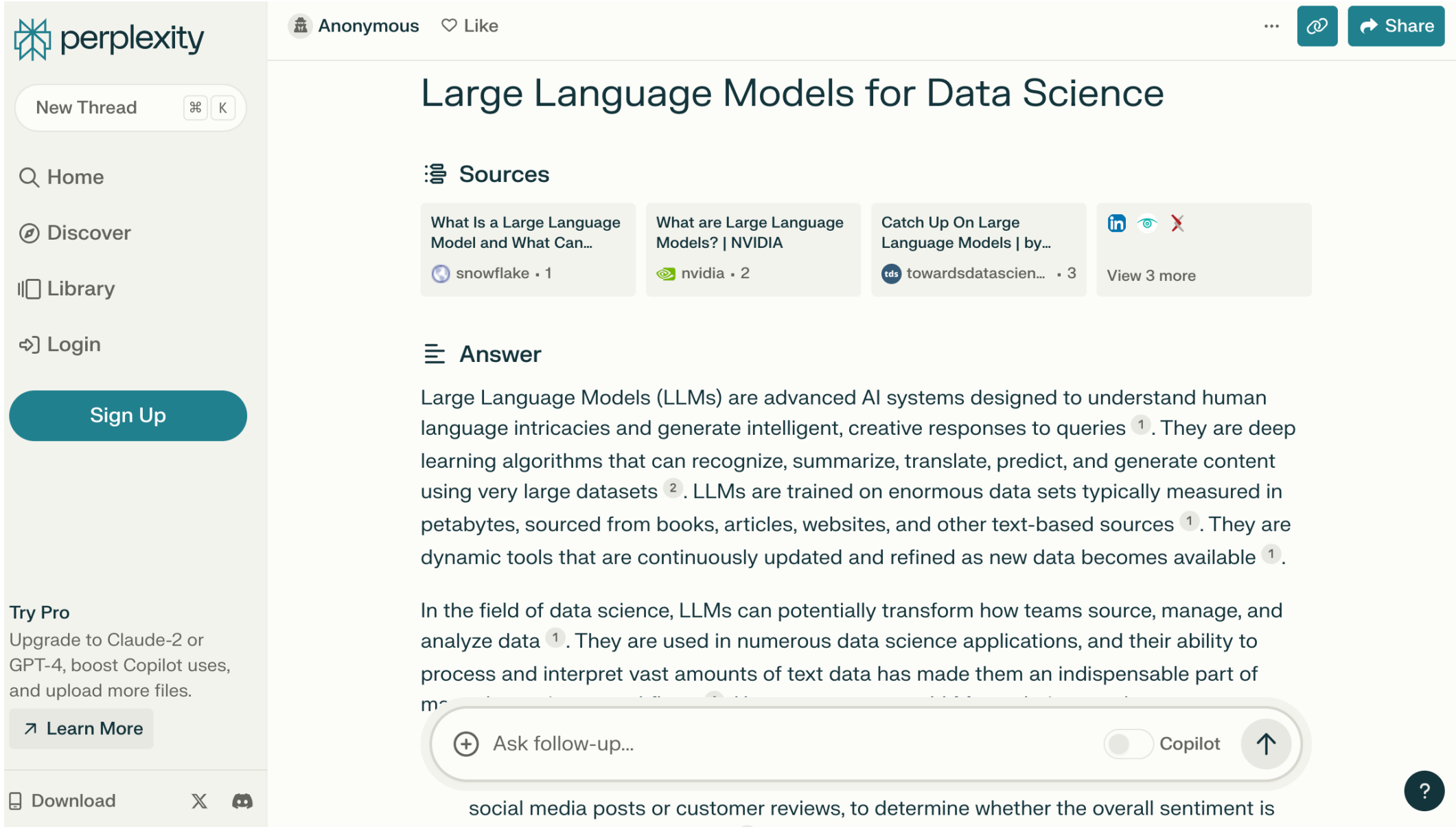
GPT-4o

Claude 3.5

Rank* (UB)	Model	Arena Score	95% CI	Votes	Organization	License	Knowledge Cutoff
1	ChatGPT-4o-latest (2024-08-08)	1316	+4/-4	24358	OpenAI	Proprietary	2023/10
2	Gemini-1.5-Pro-Exp-0827	1301	+5/-5	19976	Google	Proprietary	2023/11
2	Gemini-1.5-Pro-Exp-0801	1298	+4/-3	25471	Google	Proprietary	2023/11
2	Grok-2-08-13	1295	+4/-6	10170	xAI	Proprietary	2024/3
5	GPT-4o-2024-05-13	1286	+3/-3	83181	OpenAI	Proprietary	2023/10
6	GPT-4o-mini-2024-07-18	1274	+4/-4	23318	OpenAI	Proprietary	2023/10
6	Gemini-1.5-Flash-Exp-0827	1270	+7/-6	6610	Google	Proprietary	2023/11
6	Claude 3.5 Sonnet	1270	+3/-3	53610	Anthropic	Proprietary	2024/4
6	Gemini Advanced App (2024-05-14)	1266	+3/-3	52225	Google	Proprietary	Online
6	Grok-2-Mini-08-13	1266	+6/-6	10939	xAI	Proprietary	2024/3
7	Meta-Llama-3.1-405b-Instruct	1266	+3/-4	24855	Meta	Llama 3.1 Community	2023/12
7	GPT-4o-2024-08-06	1262	+7/-5	14960	OpenAI	Proprietary	2023/10
10	Gemini-1.5-Pro-001	1259	+3/-3	74909	Google	Proprietary	2023/11

https://lmarena.ai/

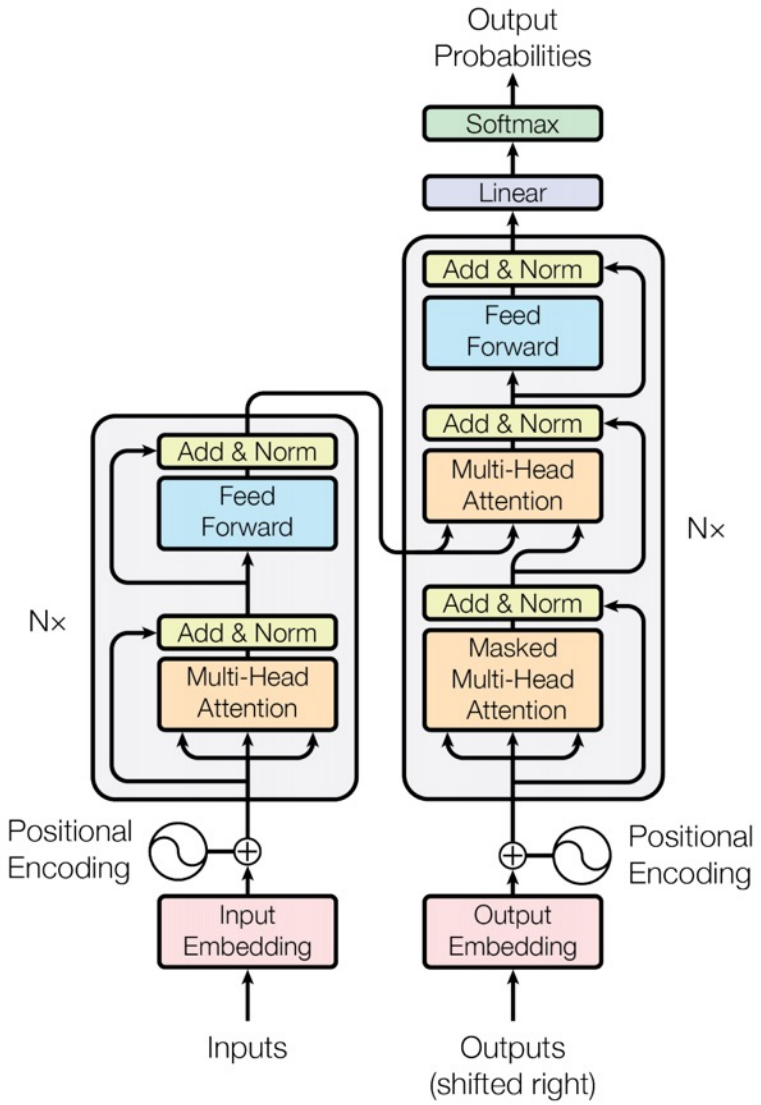
Perplexity.ai



https://www.perplexity.ai/

Transformer (Attention is All You Need)

(Vaswani et al., 2017)

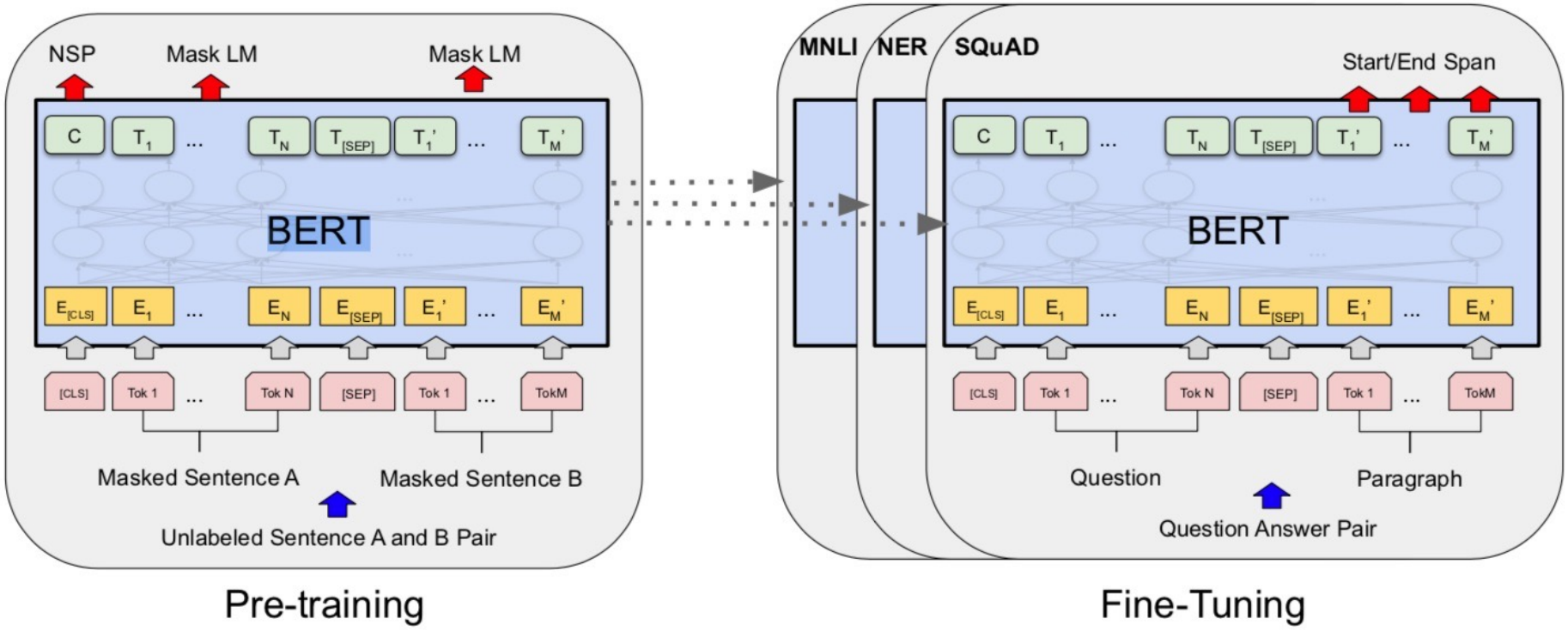


Source: Vaswani, Ashish, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N. Gomez, Łukasz Kaiser, and Illia Polosukhin. "Attention is all you need." In *Advances in neural information processing systems*, pp. 5998-6008. 2017.

BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding

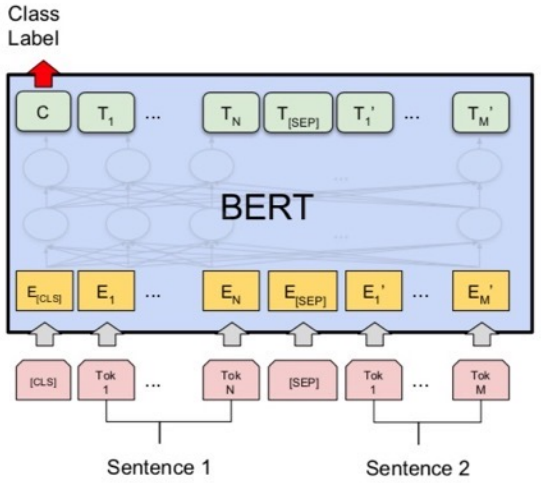
BERT (Bidirectional Encoder Representations from Transformers)

Overall pre-training and fine-tuning procedures for BERT

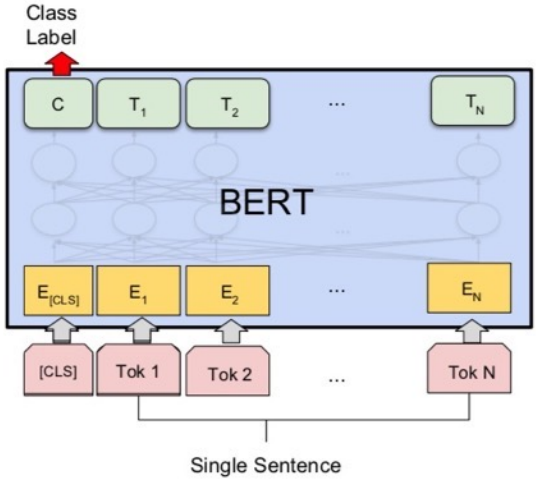


Source: Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova (2018).
"Bert: Pre-training of deep bidirectional transformers for language understanding." arXiv preprint arXiv:1810.04805.

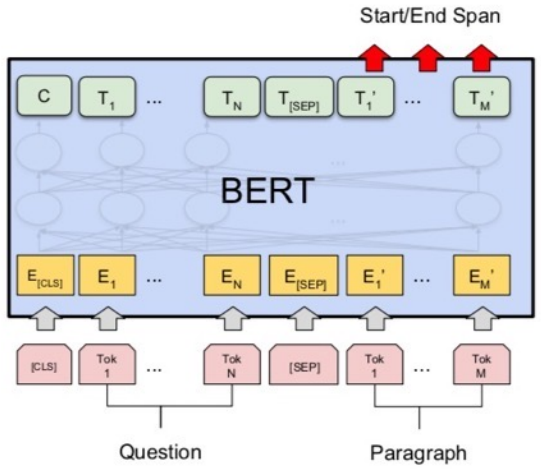
Fine-tuning BERT on Different Tasks



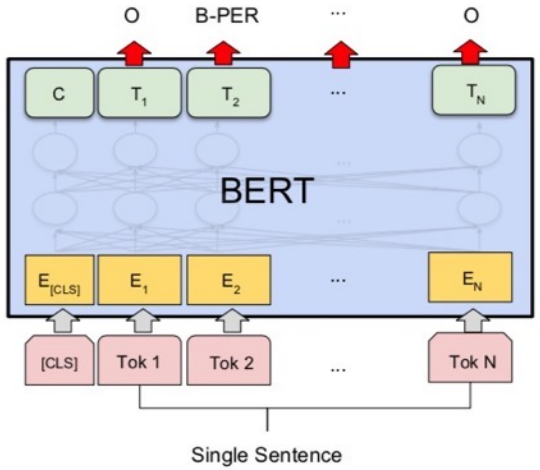
(a) Sentence Pair Classification Tasks: MNLI, QQP, QNLI, STS-B, MRPC, RTE, SWAG



(b) Single Sentence Classification Tasks: SST-2, CoLA



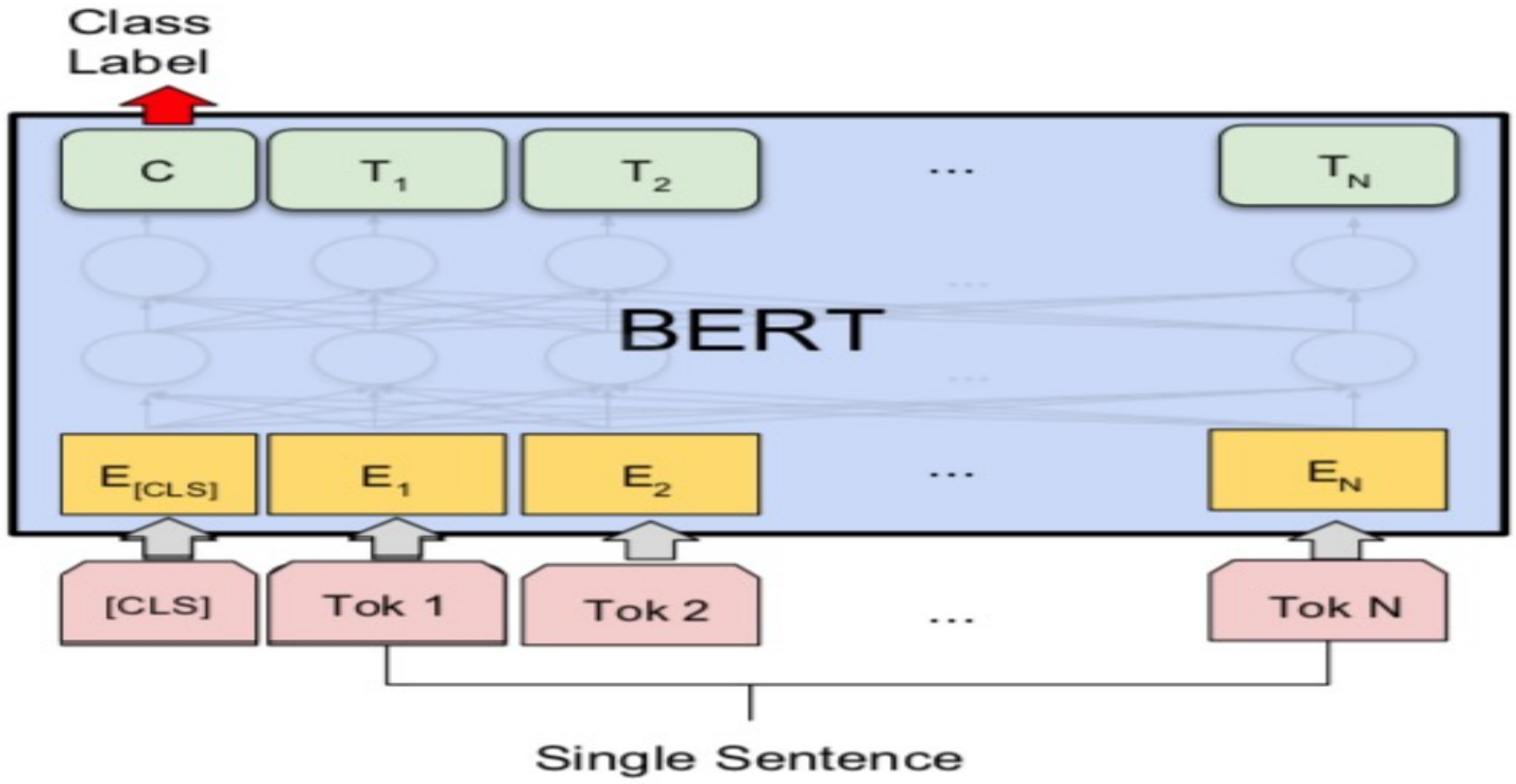
(c) Question Answering Tasks: SQuAD v1.1



(d) Single Sentence Tagging Tasks: CoNLL-2003 NER

Source: Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova (2018). "Bert: Pre-training of deep bidirectional transformers for language understanding." arXiv preprint arXiv:1810.04805.

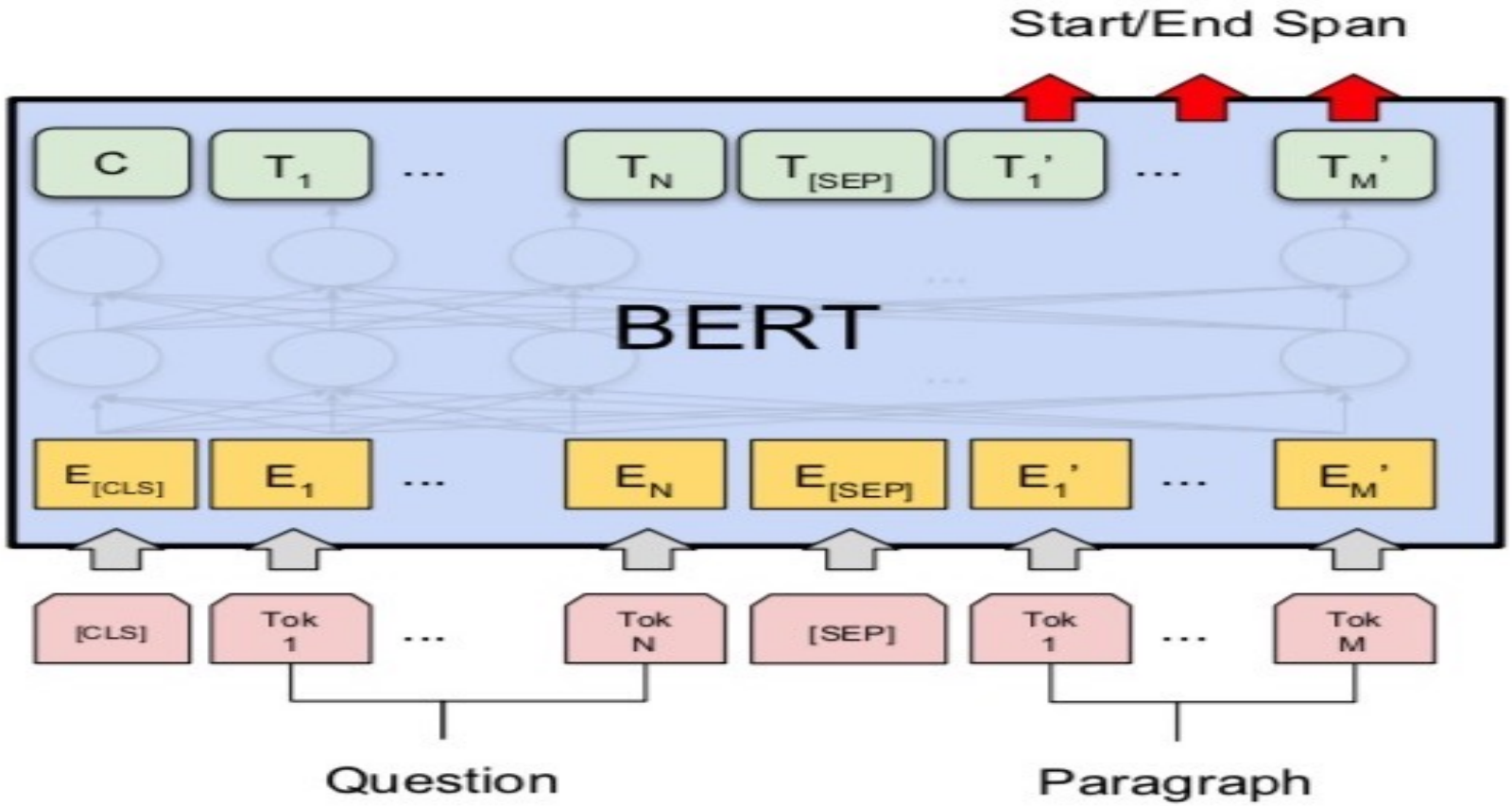
Sentiment Analysis: Single Sentence Classification



(b) Single Sentence Classification Tasks: SST-2, CoLA

Source: Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova (2018). "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding." arXiv preprint arXiv:1810.04805

Fine-tuning BERT on Question Answering (QA)

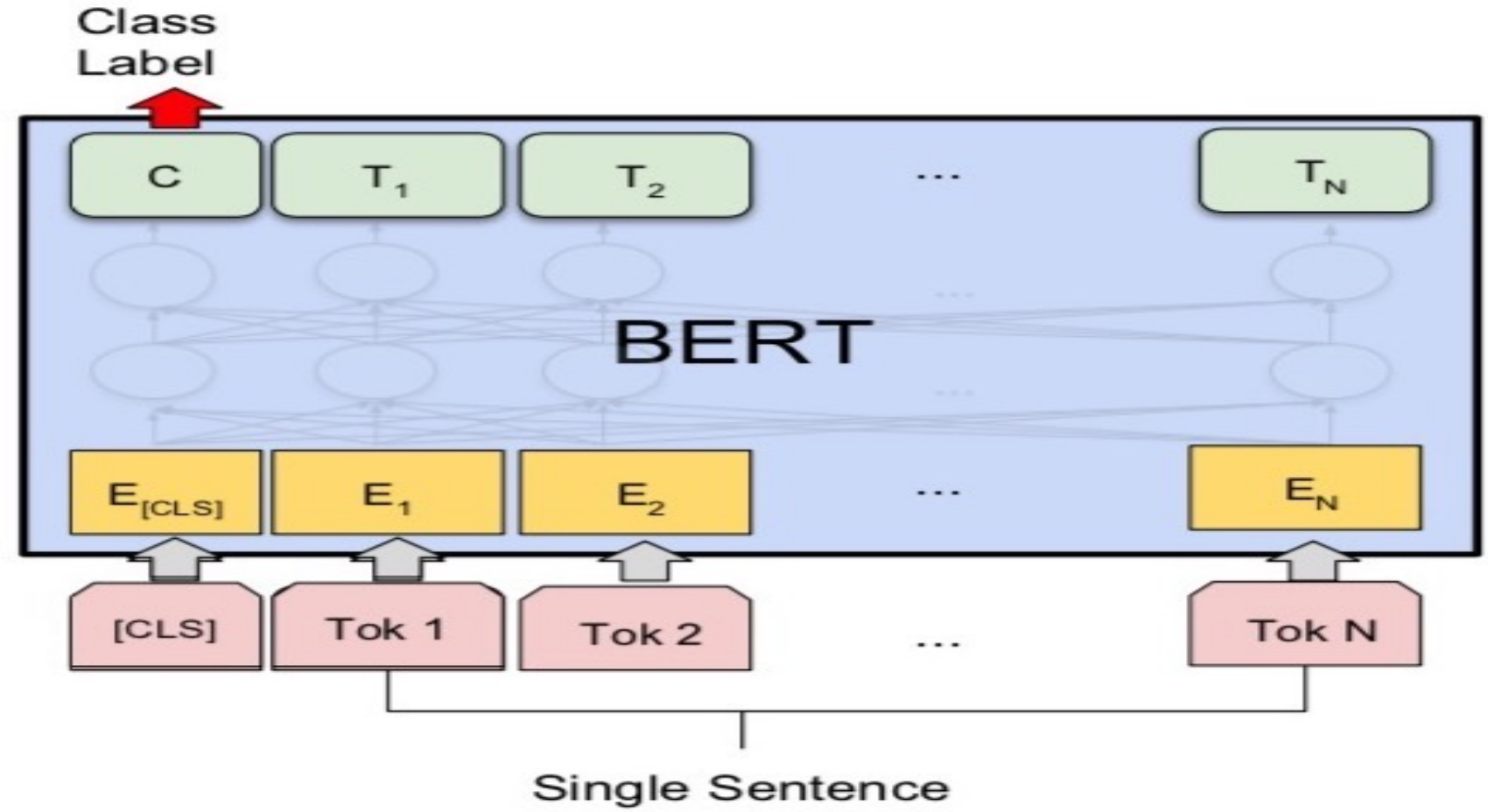


(c) Question Answering Tasks: SQuAD v1.1

Source: Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova (2018). "Bert: Pre-training of deep bidirectional transformers for language understanding." arXiv preprint arXiv:1810.04805.

Fine-tuning BERT on Dialogue

Intent Detection (ID; Classification)

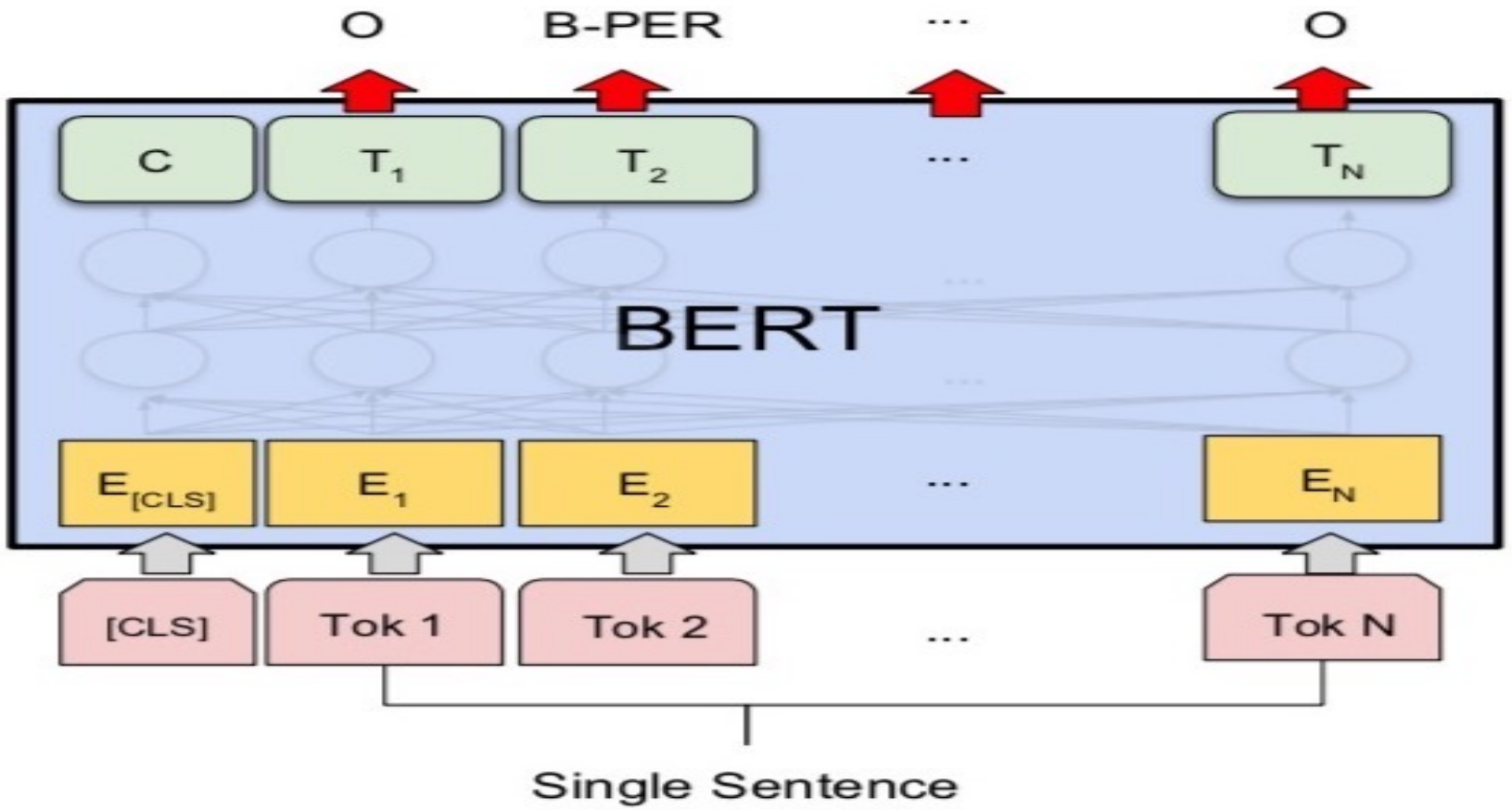


(b) Single Sentence Classification Tasks: SST-2, CoLA

Source: Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova (2018). "Bert: Pre-training of deep bidirectional transformers for language understanding." arXiv preprint arXiv:1810.04805.

Fine-tuning BERT on Dialogue

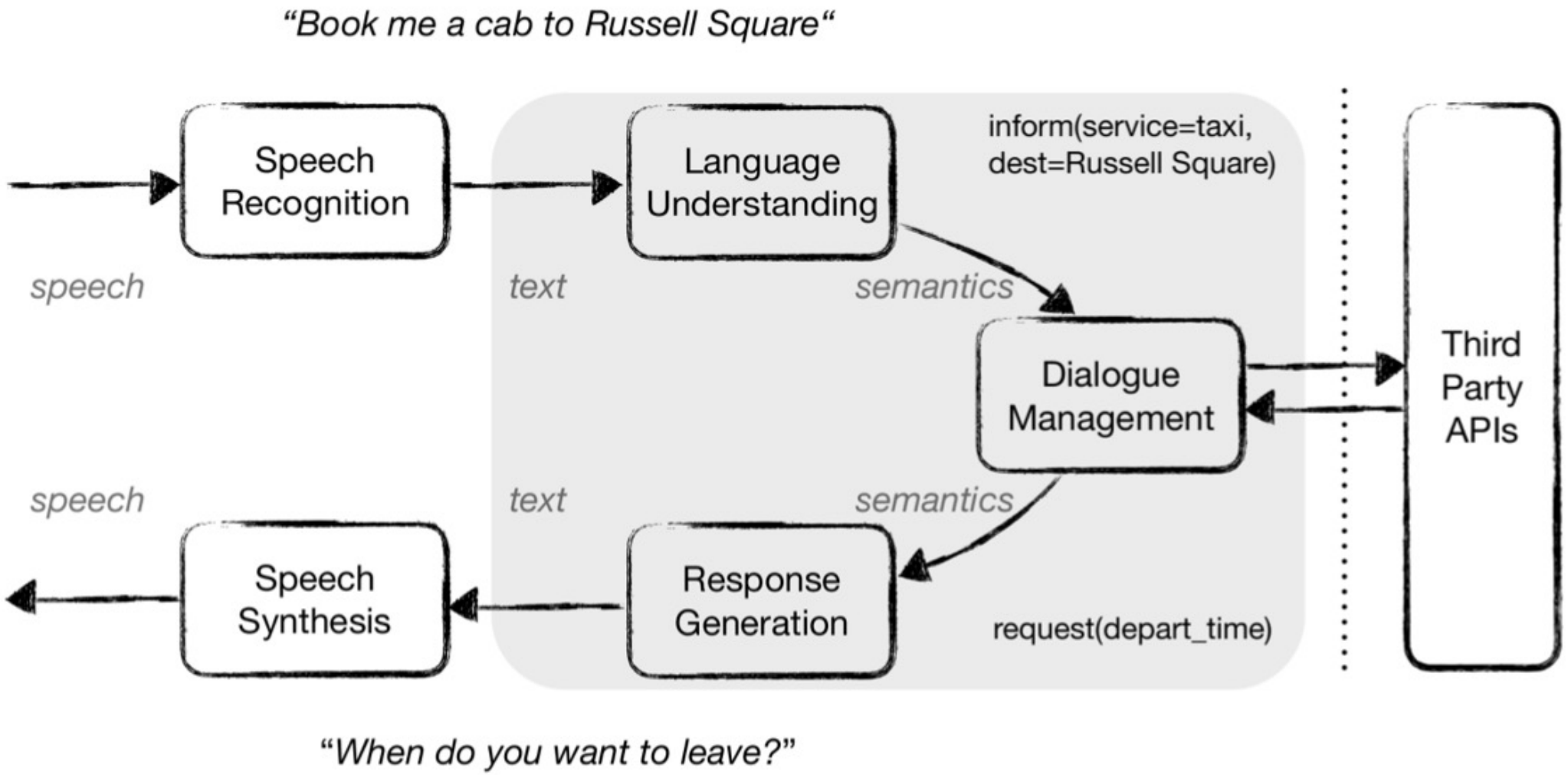
Slot Filling (SF)



(d) Single Sentence Tagging Tasks: CoNLL-2003 NER

Source: Devlin, Jacob, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova (2018). "Bert: Pre-training of deep bidirectional transformers for language understanding." arXiv preprint arXiv:1810.04805.

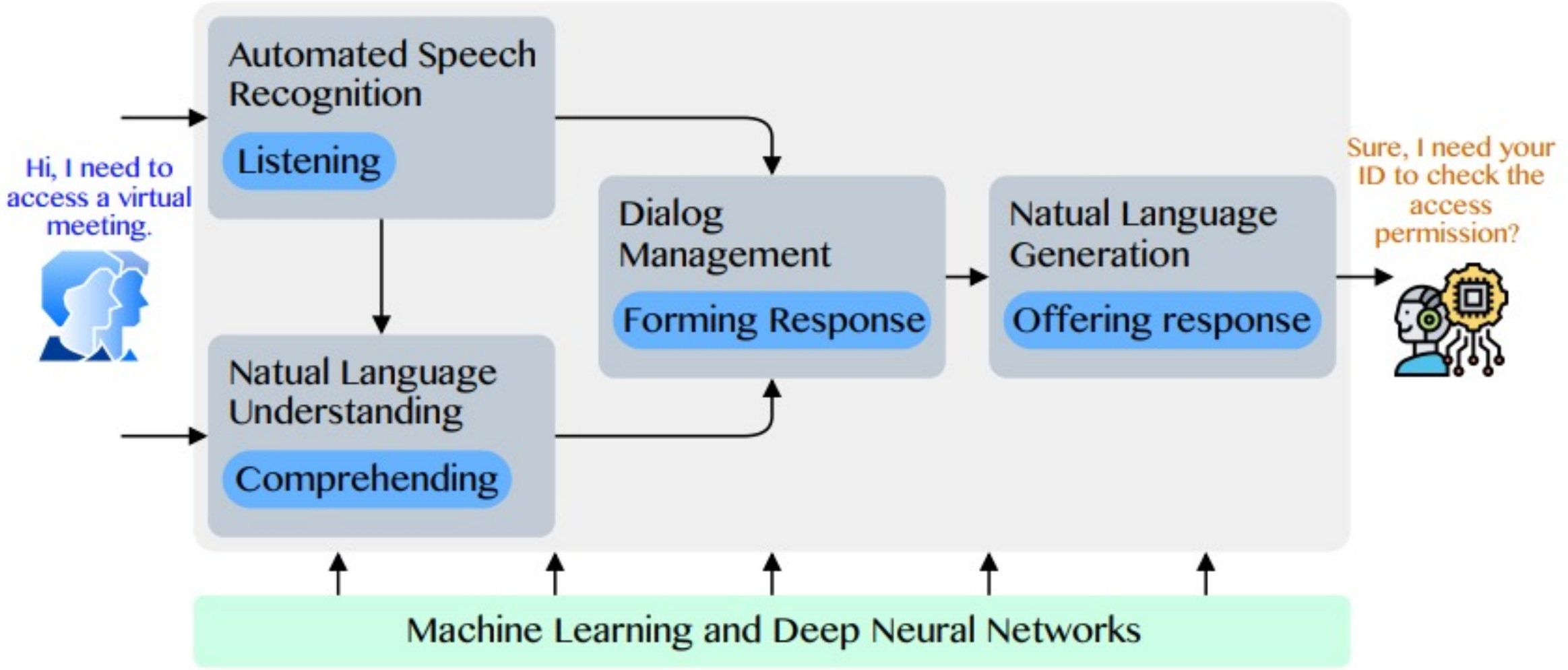
Task-Oriented Dialogue (ToD) System
Speech, Text, NLP



Source: Razumovskaia, Evgeniia, Goran Glavas, Olga Majewska, Edoardo M. Ponti, Anna Korhonen, and Ivan Vulic.
"Crossing the conversational chasm: A primer on natural language processing for multilingual task-oriented dialogue systems." Journal of Artificial Intelligence Research 74 (2022): 1351-1402.

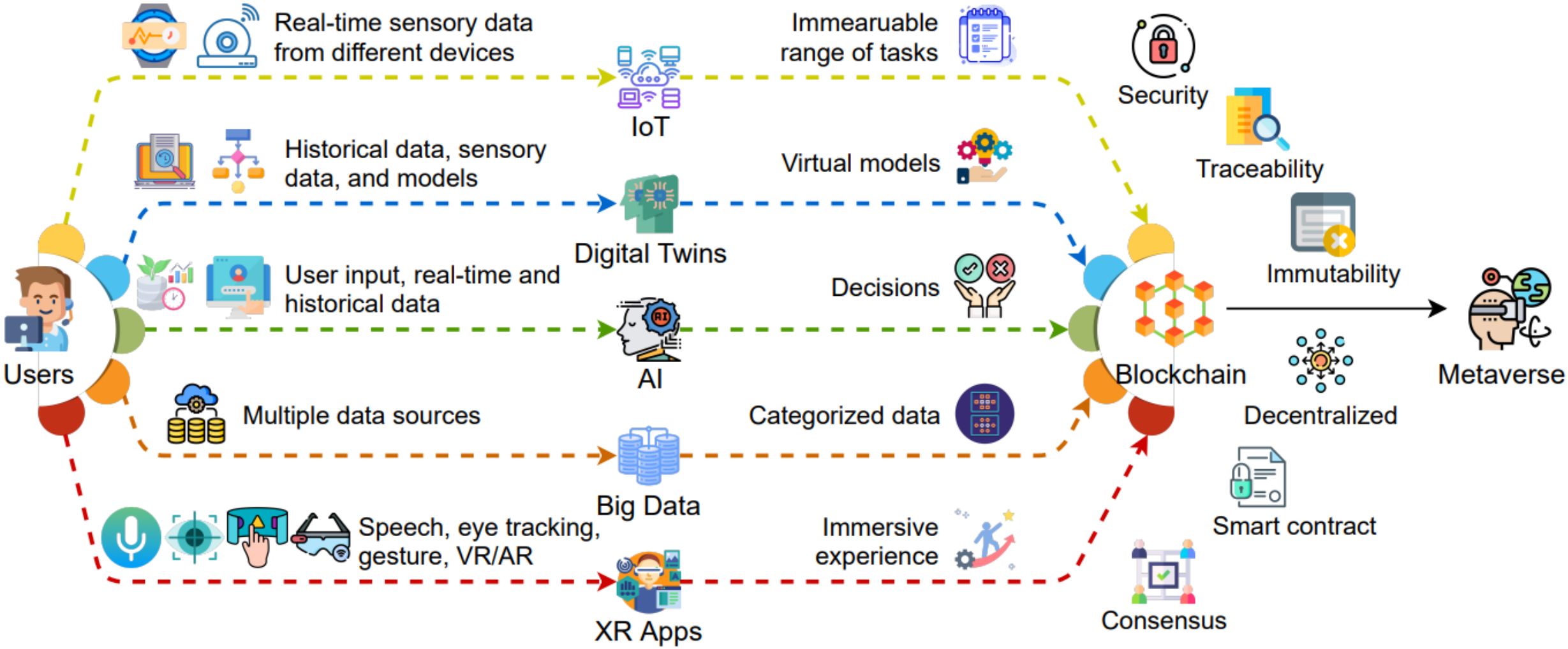
Conversational AI

to deliver contextual and personal experience to users



Source: Huynh-The, Thien, Quoc-Viet Pham, Xuan-Qui Pham, Thanh Thi Nguyen, Zhu Han, and Dong-Seong Kim (2022). "Artificial Intelligence for the Metaverse: A Survey." arXiv preprint arXiv:2202.10336.

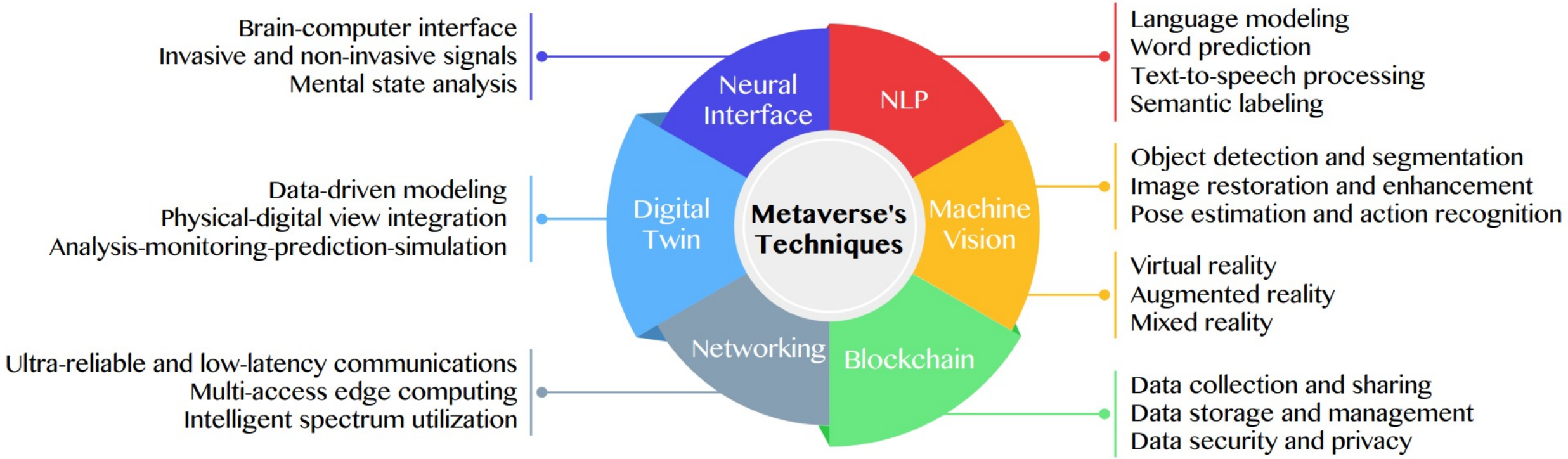
AI and Blockchain
Key Enabling Technologies of the Metaverse



Source: Gadekallu, Thippa Reddy, Thien Huynh-The, Weizheng Wang, Gokul Yenduri, Pasika Ranaweera, Quoc-Viet Pham, Daniel Benevides da Costa, and Madhusanka Liyanage (2022). "Blockchain for the Metaverse: A Review." arXiv preprint arXiv:2203.09738..

Primary Technical Aspects in the Metaverse

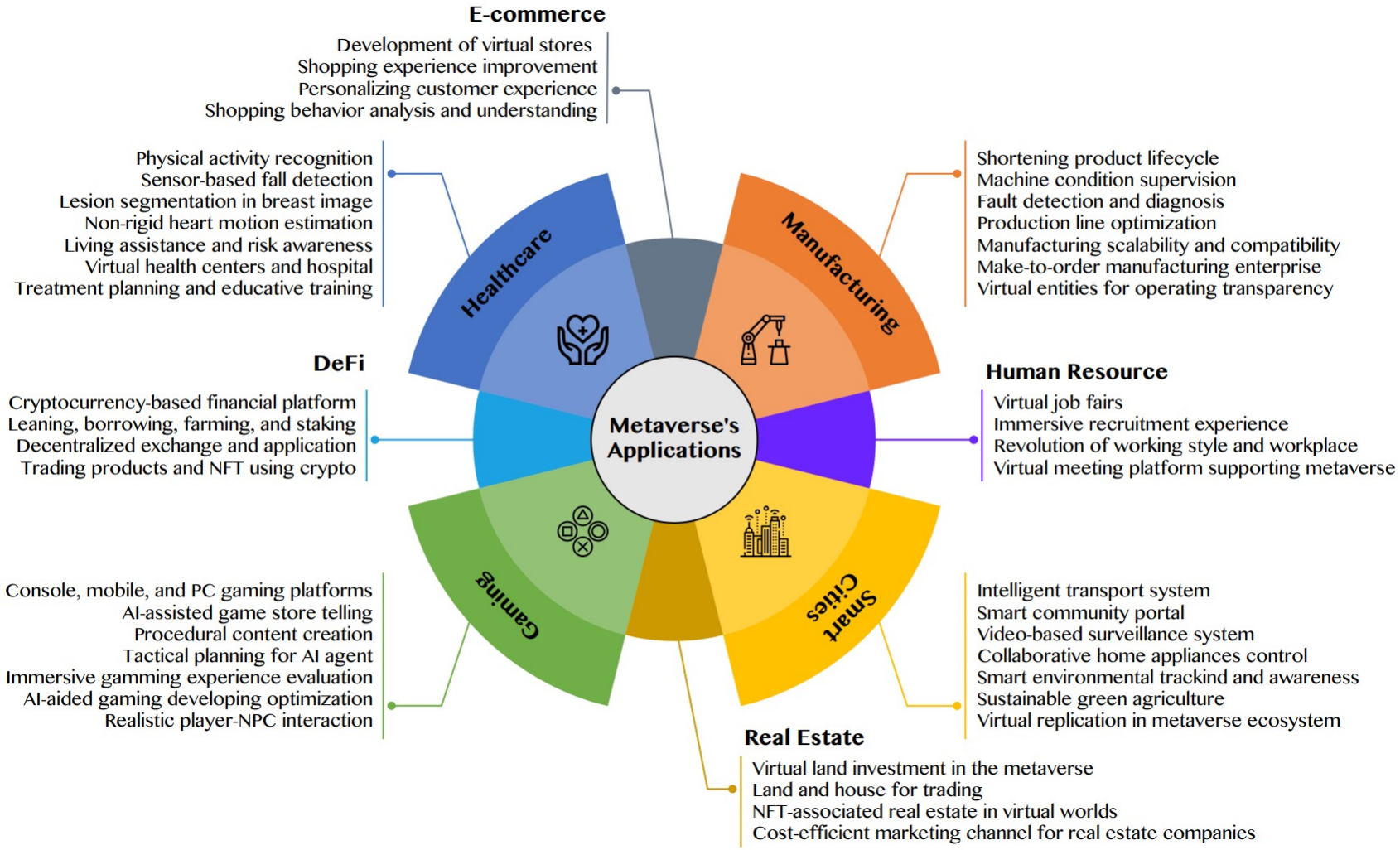
AI with ML algorithms and DL architectures is advancing the user experience in the virtual world



Source: Huynh-The, Thien, Quoc-Viet Pham, Xuan-Qui Pham, Thanh Thi Nguyen, Zhu Han, and Dong-Seong Kim (2022). "Artificial Intelligence for the Metaverse: A Survey." arXiv preprint arXiv:2202.10336.

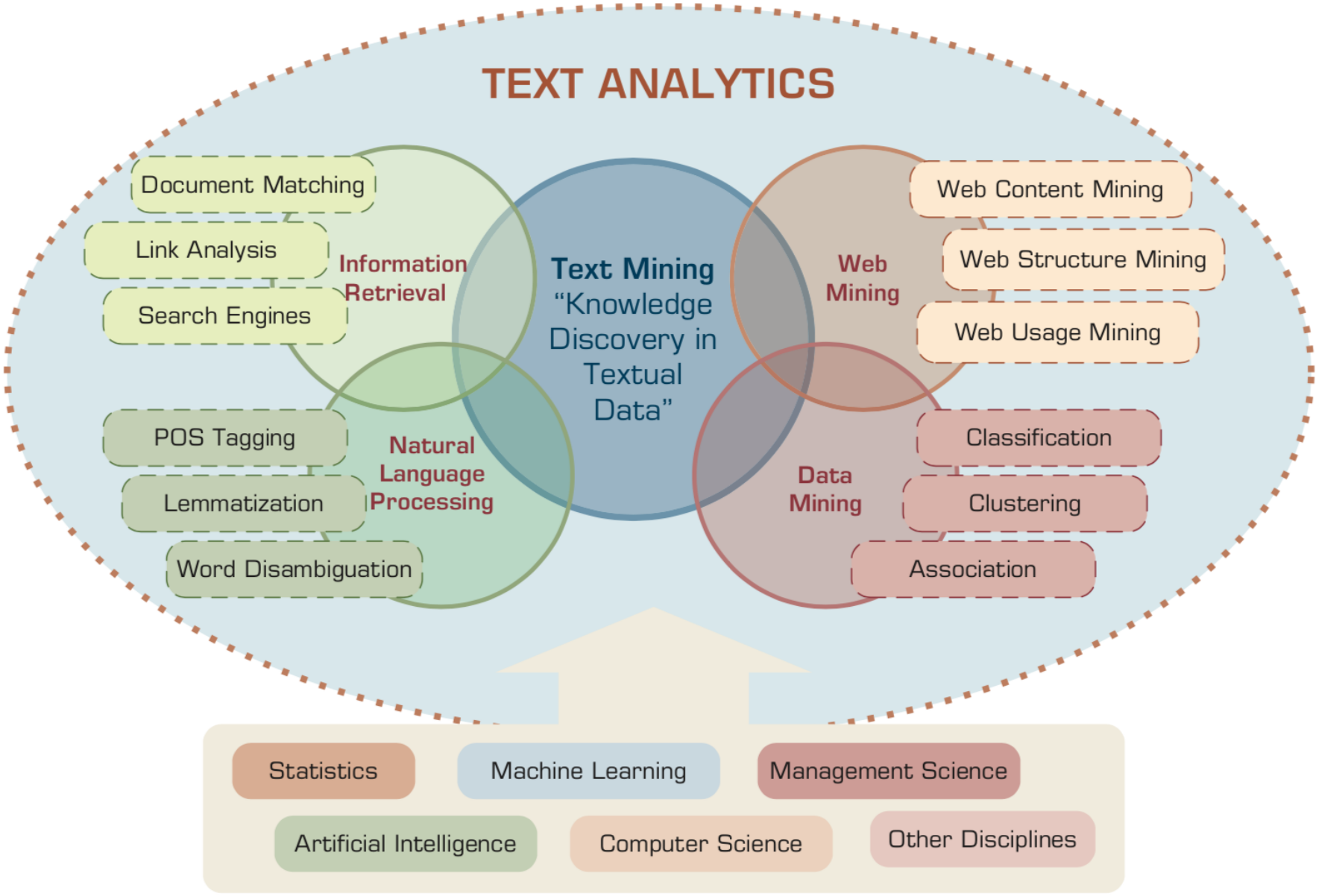
AI for the Metaverse in the Application Aspects

healthcare, manufacturing, smart cities, gaming
E-commerce, human resources, real estate, and DeFi



Source: Huynh-The, Thien, Quoc-Viet Pham, Xuan-Qui Pham, Thanh Thi Nguyen, Zhu Han, and Dong-Seong Kim (2022). "Artificial Intelligence for the Metaverse: A Survey." arXiv preprint arXiv:2202.10336.

AI for Text Analytics



Source: Ramesh Sharda, Dursun Delen, and Efraim Turban (2017), Business Intelligence, Analytics, and Data Science: A Managerial Perspective, 4th Edition, Pearson

4 Approaches of AI

2. **Thinking Humanly:** **The Cognitive Modeling Approach**	**3.** **Thinking Rationally:** **The "Laws of Thought" Approach**
1. **Acting Humanly:** **The Turing Test Approach** (1950)	**4.** **Acting Rationally:** **The Rational Agent Approach**

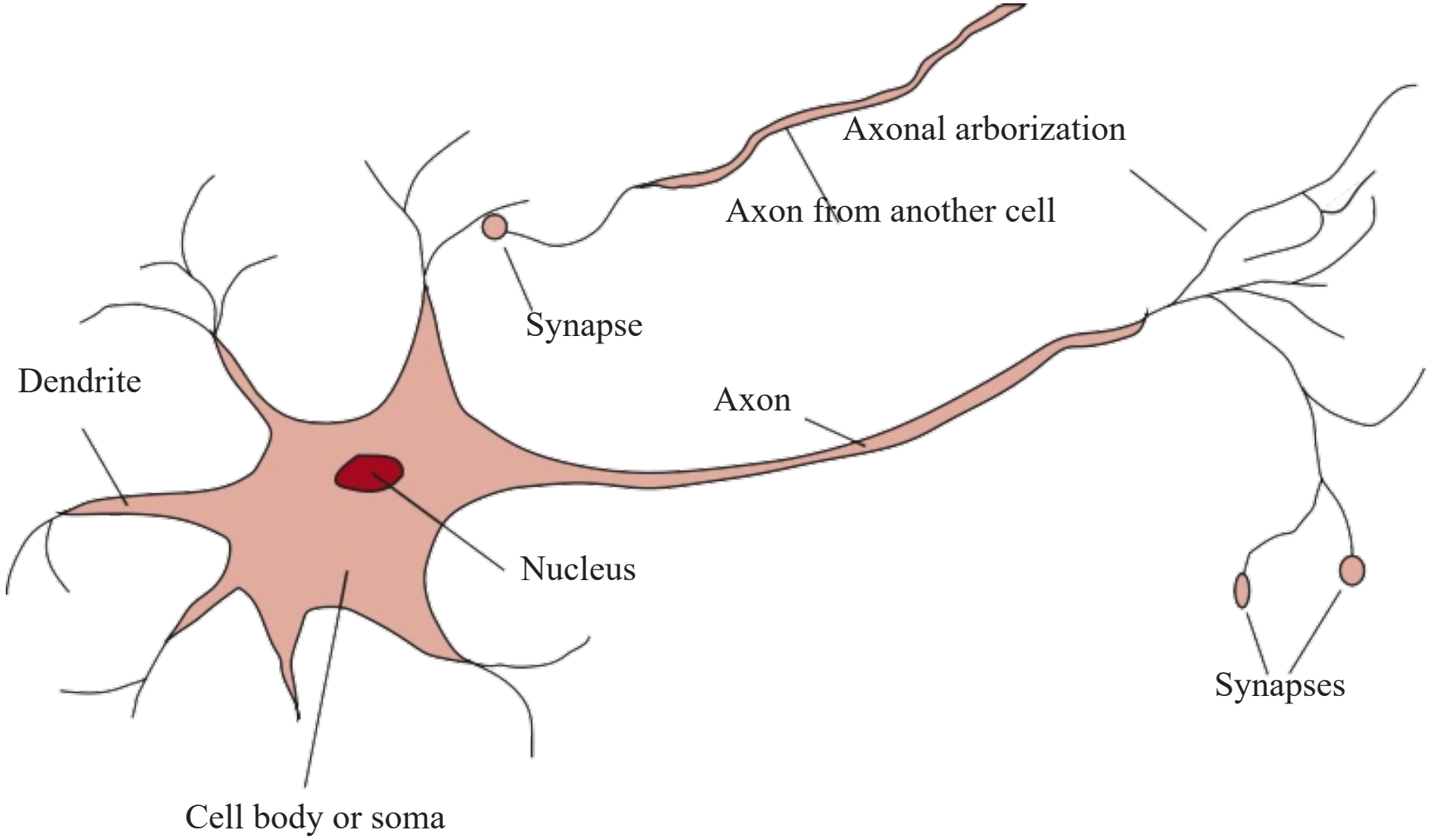
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Acting Rationally:
The Rational Agent Approach

- AI has focused on the study and construction of agents that **do the right thing.**
- **Standard model**

Neuroscience

The parts of a nerve cell or neuron



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

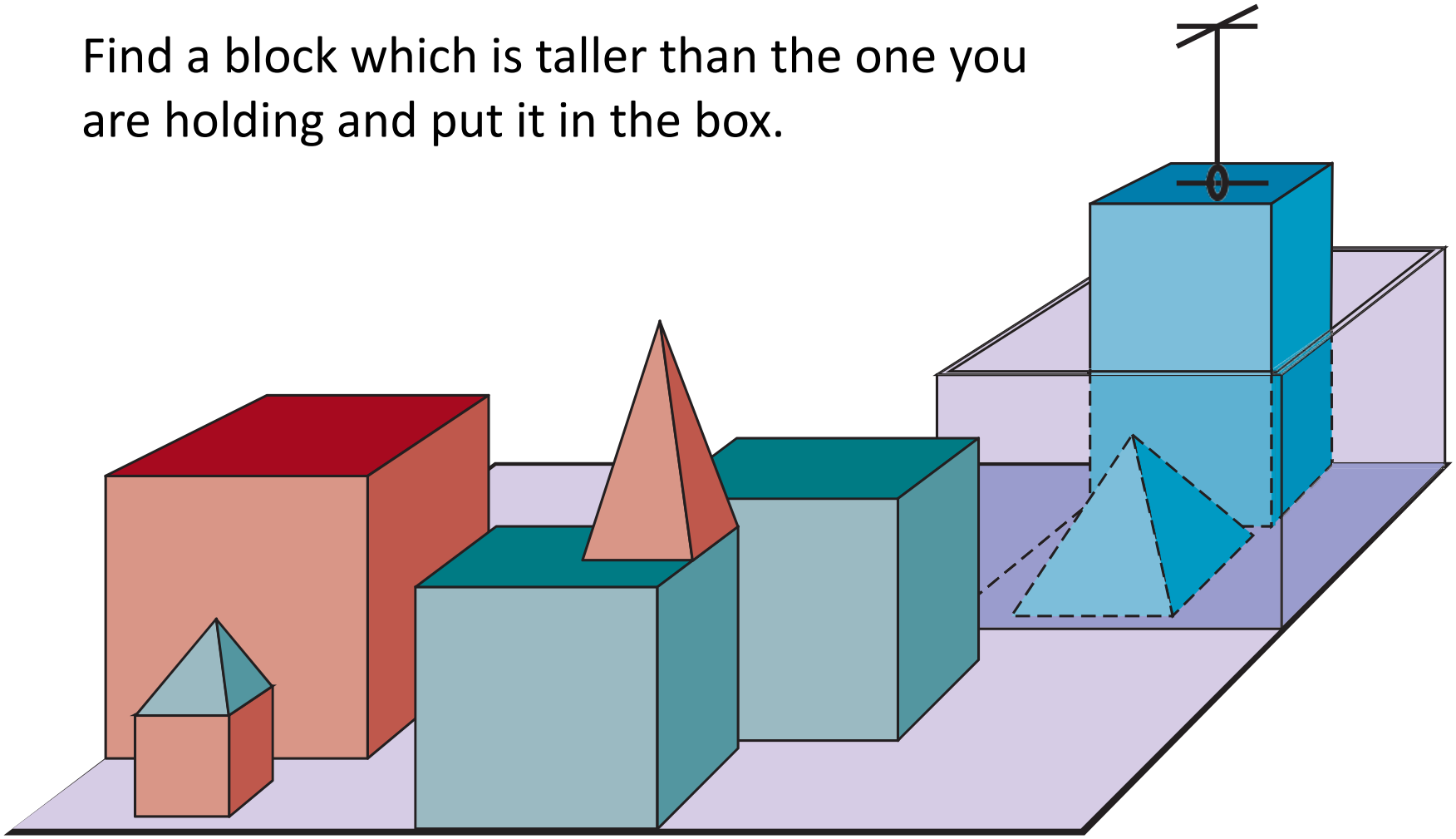
Comparison of Computer and Human Brain

	Supercomputer	Personal Computer	Human Brain
Computational units	10^6 GPUs + CPUs	8 CPU cores	10^6 columns
	10^{15} transistors	10^{10} transistors	10^{11} neurons
Storage units	10^{16} bytes RAM	10^{10} bytes RAM	10^{11} neurons
	10^{17} bytes disk	10^{12} bytes disk	10^{14} synapses
Cycle time	10^{-9} sec	10^{-9} sec	10^{-3} sec
Operations/sec	10^{18}	10^{10}	10^{17}

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A scene from the blocks world

Find a block which is taller than the one you are holding and put it in the box.



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

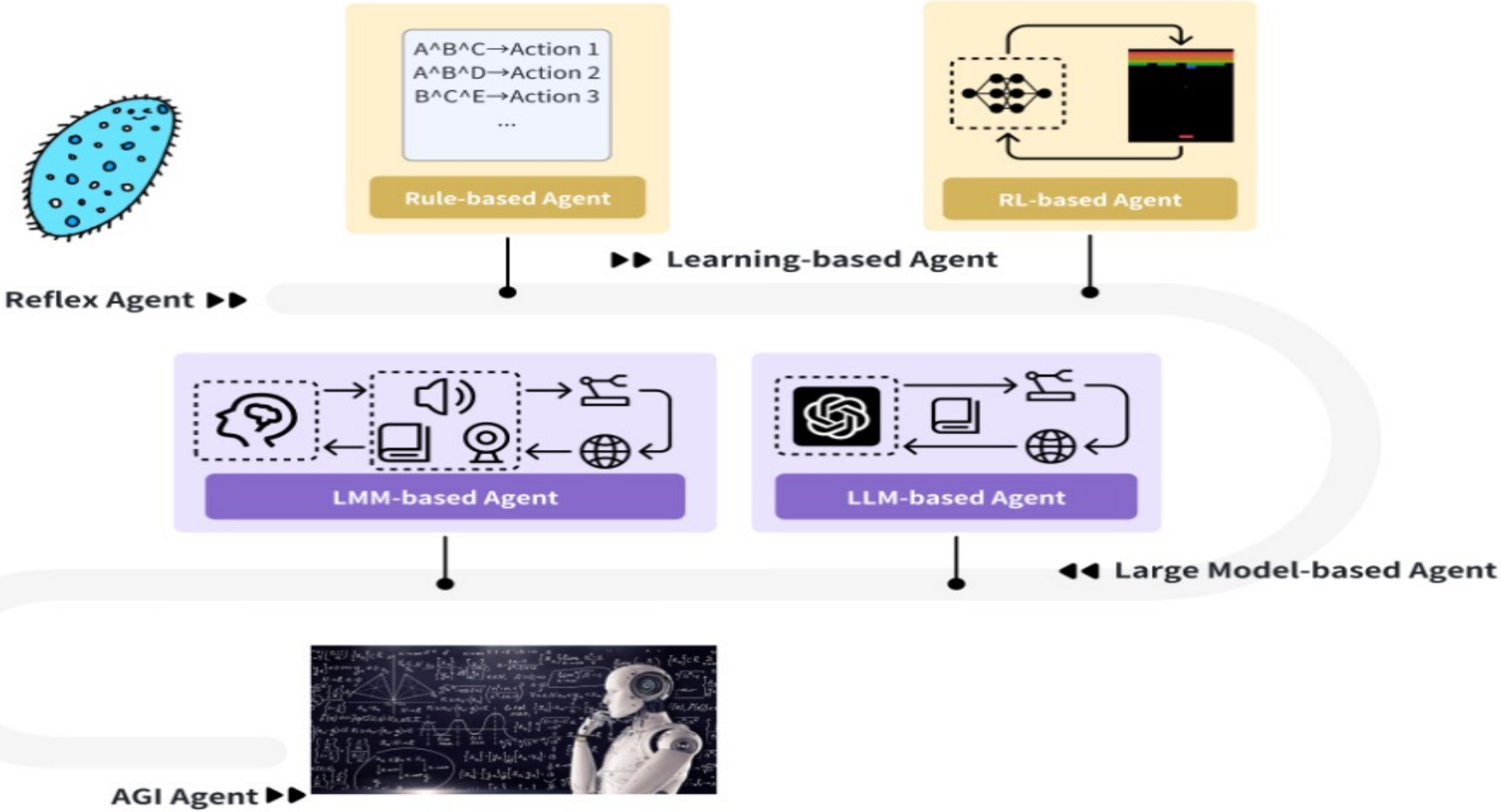
Intelligent Agents

4 Approaches of AI

2. **Thinking Humanly: The Cognitive Modeling Approach**	**3.** **Thinking Rationally: The "Laws of Thought" Approach**
1. **Acting Humanly: The Turing Test Approach** (1950)	**4.** **Acting Rationally: The Rational Agent Approach**

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Intelligent Agents Roadmap



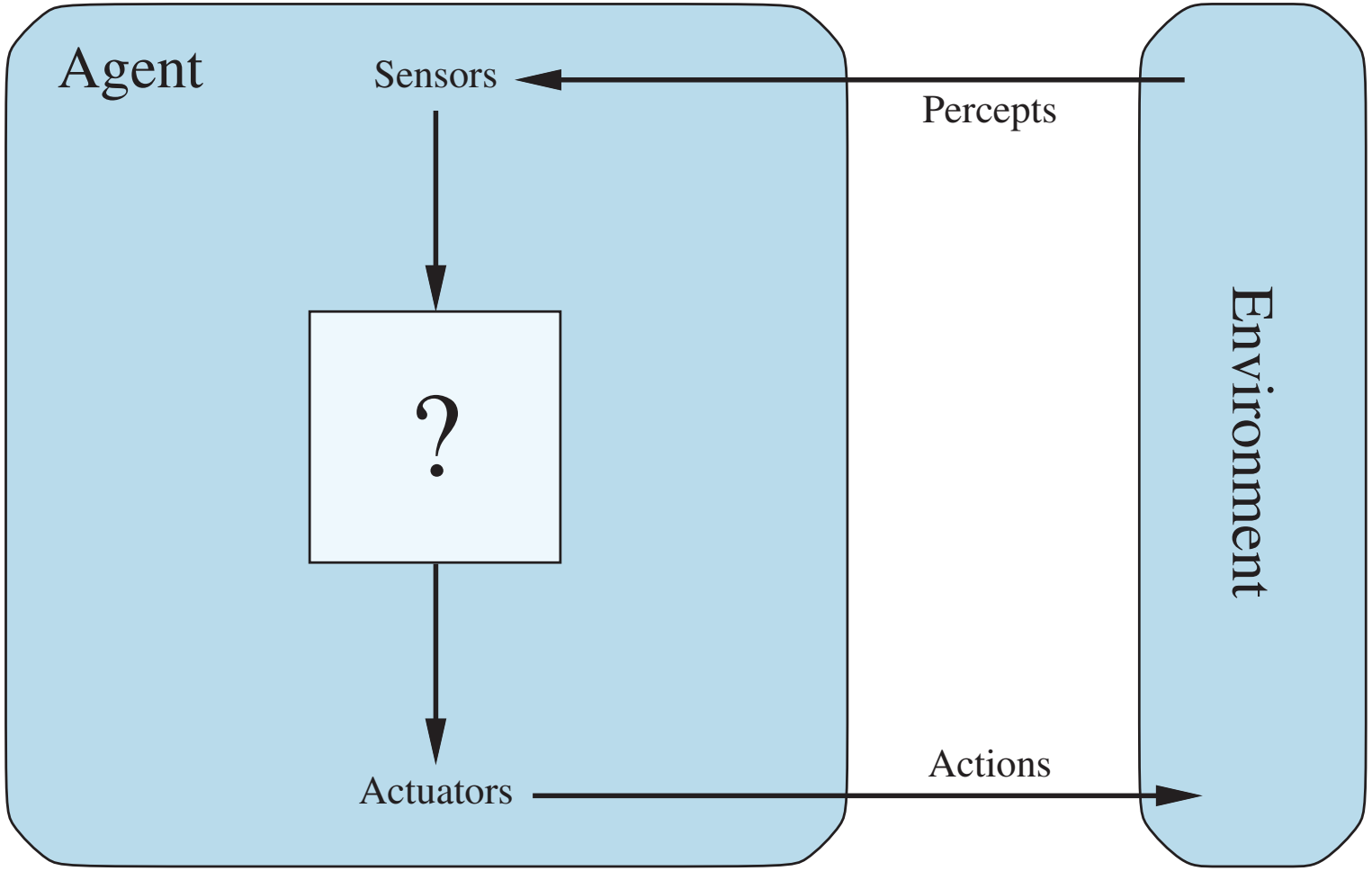
Source: Cheng, Yuheng, Ceyao Zhang, Zhengwen Zhang, Xiangrui Meng, Sirui Hong, Wenhao Li, Zihao Wang et al. "Exploring large language model based intelligent agents: Definitions, methods, and prospects." arXiv preprint arXiv:2401.03428 (2024).

AI Agents

- Traditional AI Agents
  - Simple reflex agents
  - Model-based reflex agents
  - Goal-based agents
  - Utility-based agents
  - Learning agents

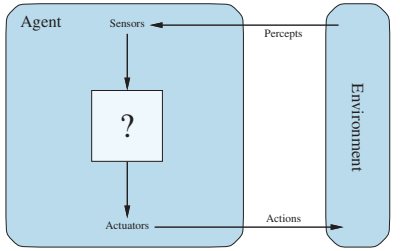
- Evolution of AI Agents
  - LLM-based Agents
  - Multi-modal agents
  - Embodied AI agents in virtual environments
  - Collaborative AI agents

Agents interact with environments through sensors and actuators



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

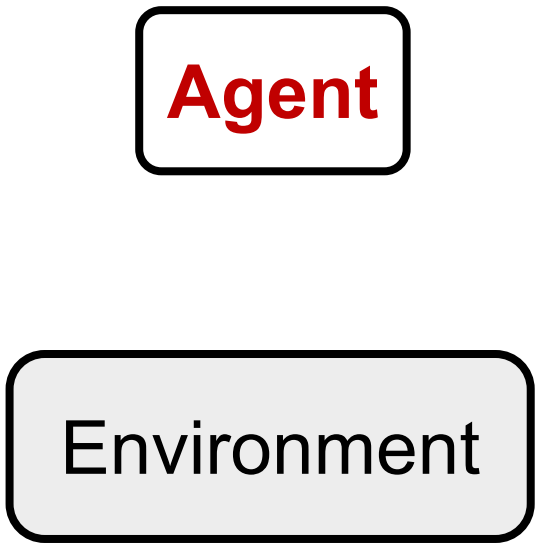
AI Agents



- **Definition: An AI agent is an entity that perceives its environment and takes actions to achieve goals**
- **Components:**
  1. **Sensors: Perceive the environment**
  2. **Actuators: Act upon the environment**
  3. **Decision-making mechanism: Process inputs and decide on actions**

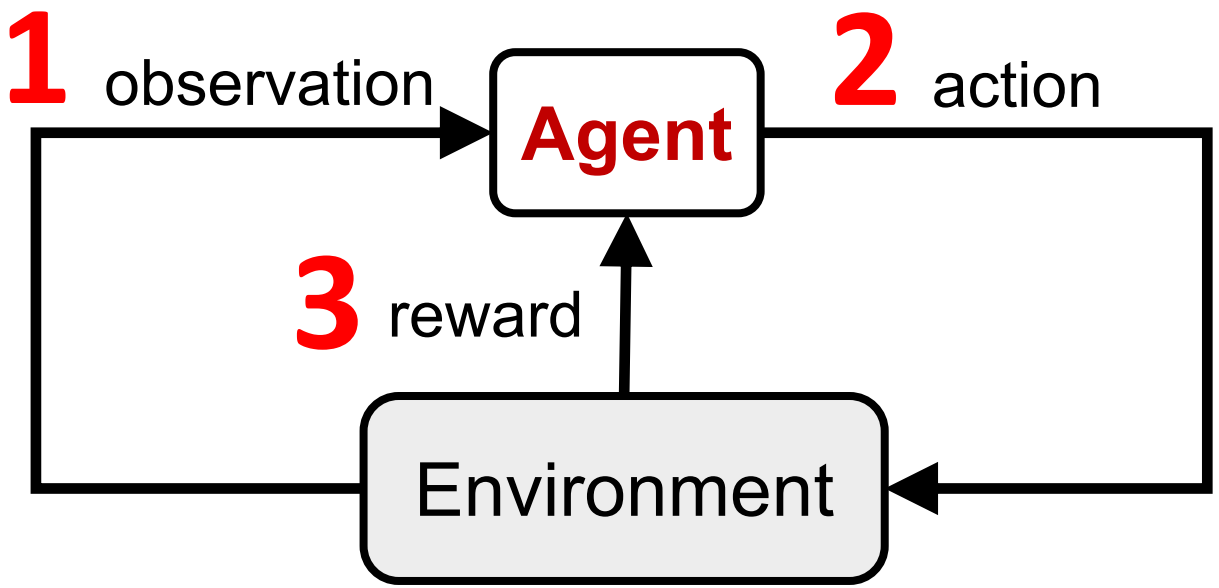
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Reinforcement Learning (DL)



Source: Richard S. Sutton & Andrew G. Barto (2018), Reinforcement Learning: An Introduction, 2nd Edition, A Bradford Book.

Reinforcement Learning (DL)



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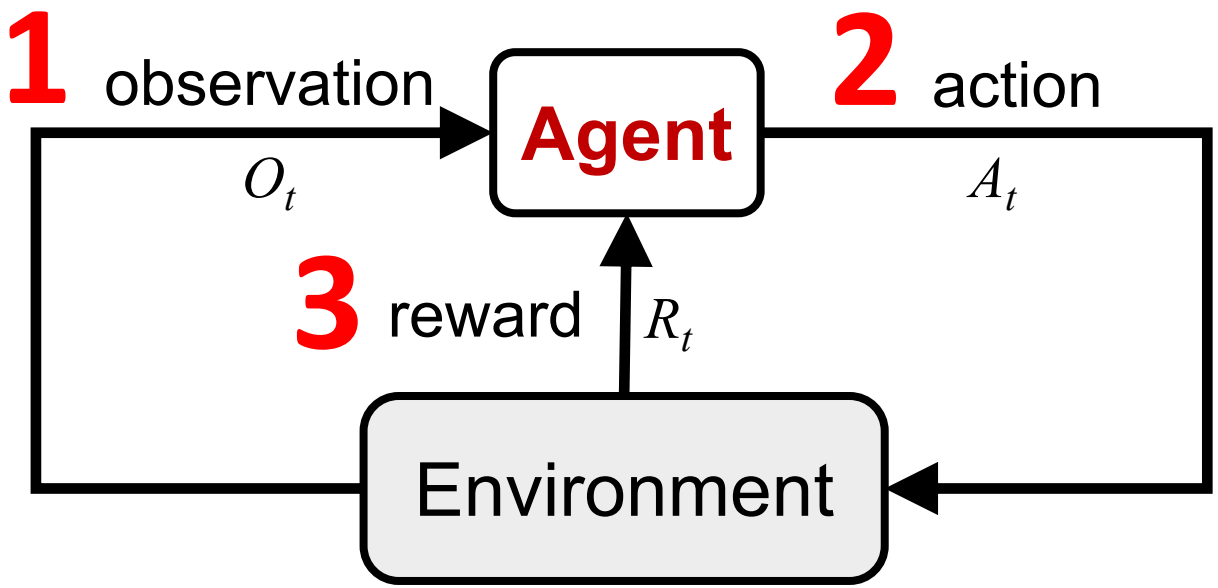
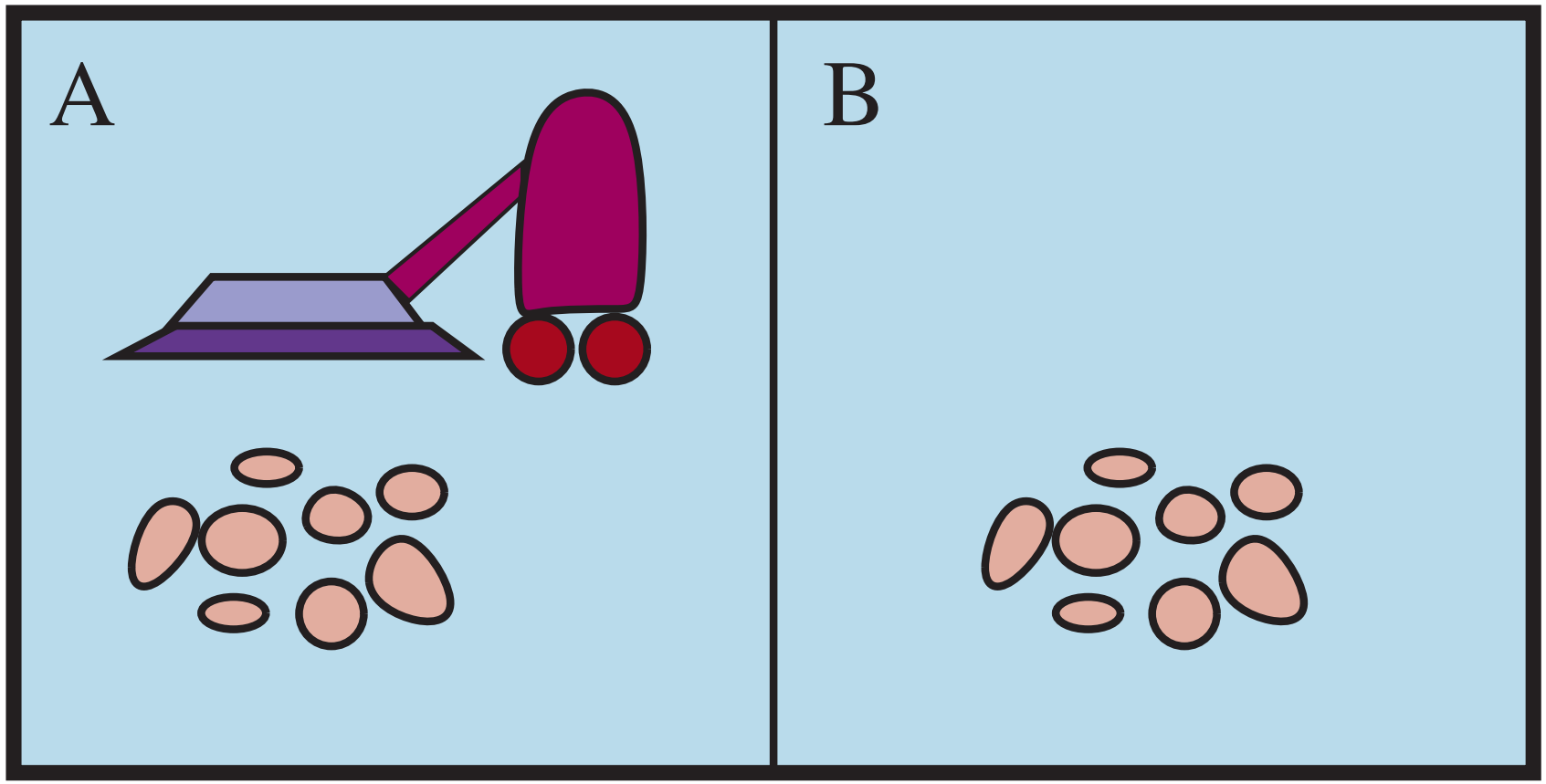
Reinforcement Learning (DL)



Source: Richard S. Sutton & Andrew G. Barto (2018), Reinforcement Learning: An Introduction, 2nd Edition, A Bradford Book.

A vacuum-cleaner world with just two locations



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Partial tabulation of a simple agent function for the vacuum-cleaner world

Percept sequence	Action
$[A, Clean]$	$Right$
$[A, Dirty]$	$Suck$
$[B, Clean]$	$Left$
$[B, Dirty]$	$Suck$
$[A, Clean], [A, Clean]$	$Right$
$[A, Clean], [A, Dirty]$	$Suck$
⋮	⋮
$[A, Clean], [A, Clean], [A, Clean]$	$Right$
$[A, Clean], [A, Clean], [A, Dirty]$	$Suck$
⋮	⋮

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

PEAS description of the task environment for an automated taxi driver

Agent Type	Performance Measure	Environment	Actuators	Sensors
Taxi driver	Safe, fast, legal, comfortable trip, maximize profits, minimize impact on other road users	Roads, other traffic, police, pedestrians, customers, weather	Steering, accelerator, brake, signal, horn, display, speech	Cameras, radar, speedometer, GPS, engine sensors, accelerometer, microphones, touchscreen

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Examples of Agent Types and their PEAS descriptions

Agent Type	Performance Measure	Environment	Actuators	Sensors
Medical diagnosis system	Healthy patient, reduced costs	Patient, hospital, staff	Display of questions, tests, diagnoses, treatments	Touchscreen/voice entry of symptoms and findings
Satellite image analysis system	Correct categorization of objects, terrain	Orbiting satellite, downlink, weather	Display of scene categorization	High-resolution digital camera
Part-picking robot	Percentage of parts in correct bins	Conveyor belt with parts; bins	Jointed arm and hand	Camera, tactile and joint angle sensors
Refinery controller	Purity, yield, safety	Refinery, raw materials, operators	Valves, pumps, heaters, stirrers, displays	Temperature, pressure, flow, chemical sensors
Interactive English tutor	Student's score on test	Set of students, testing agency	Display of exercises, feedback, speech	Keyboard entry, voice

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Examples of Task Environments and their Characteristics

Task Environment	Observable	Agents	Deterministic	Episodic	Static	Discrete
Crossword puzzle	Fully	Single	Deterministic	Sequential	Static	Discrete
Chess with a clock	Fully	Multi	Deterministic	Sequential	Semi	Discrete
Poker	Partially	Multi	Stochastic	Sequential	Static	Discrete
Backgammon	Fully	Multi	Stochastic	Sequential	Static	Discrete
Taxi driving	Partially	Multi	Stochastic	Sequential	Dynamic	Continuous
Medical diagnosis	Partially	Single	Stochastic	Sequential	Dynamic	Continuous
Image analysis	Fully	Single	Deterministic	Episodic	Semi	Continuous
Part-picking robot	Partially	Single	Stochastic	Episodic	Dynamic	Continuous
Refinery controller	Partially	Single	Stochastic	Sequential	Dynamic	Continuous
English tutor	Partially	Multi	Stochastic	Sequential	Dynamic	Discrete

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

The TABLE-DRIVEN-AGENT program is invoked for each new percept and returns an action each time.

It retains the complete percept sequence in memory.

function TABLE-DRIVEN-AGENT(*percept*) **returns** an action

  persistent: *percepts*, a sequence, initially empty

    table, a table of actions, indexed by percept sequences, initially fully specified

  append *percept* to the end of *percepts*

  action ← LOOKUP(*percepts*, *table*)

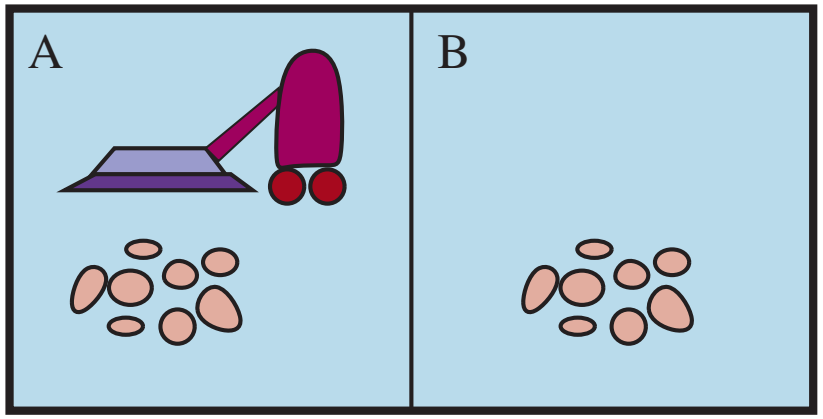
  return *action*

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

The agent program for a simple reflex agent in the two-location vacuum environment.

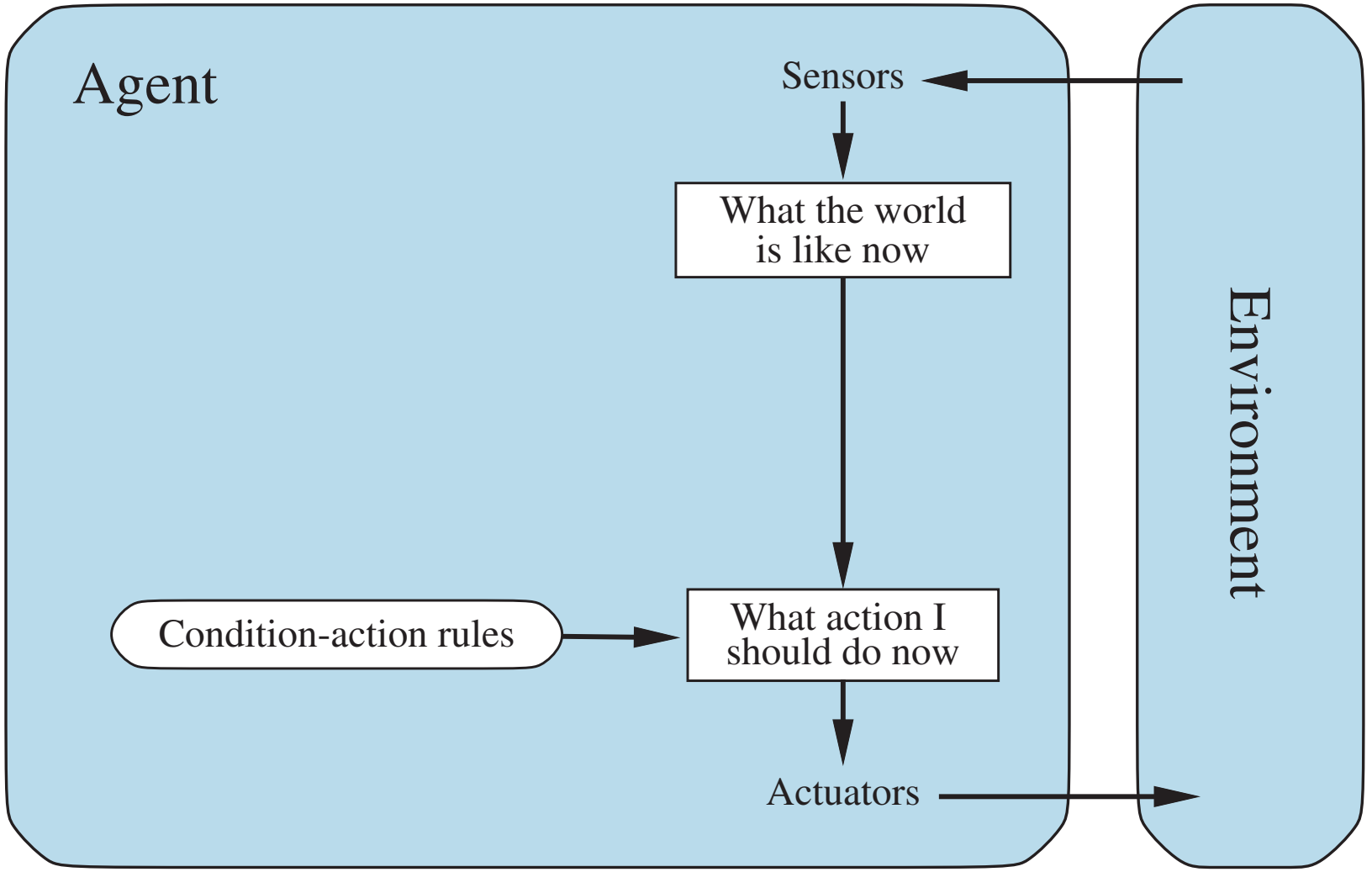
function REFLEX-VACUUM-AGENT($[location, status]$) **returns** an action

if $status$ = $Dirty$ **then return** $Suck$
else if $location$ = A **then return** $Right$
else if $location$ = B **then return** $Left$



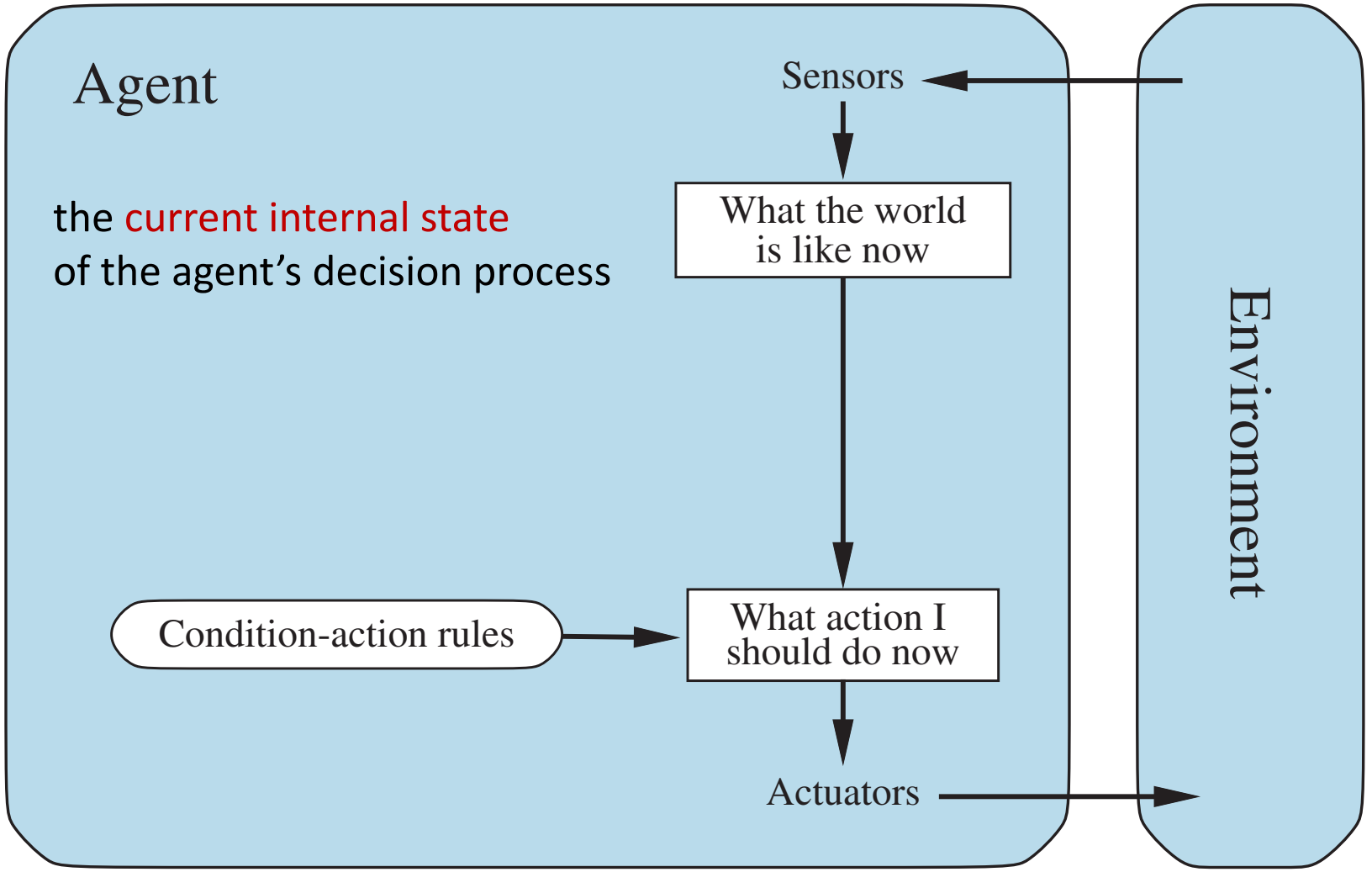
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Schematic Diagram of a Simple Reflex Agent



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Schematic diagram of a simple reflex agent



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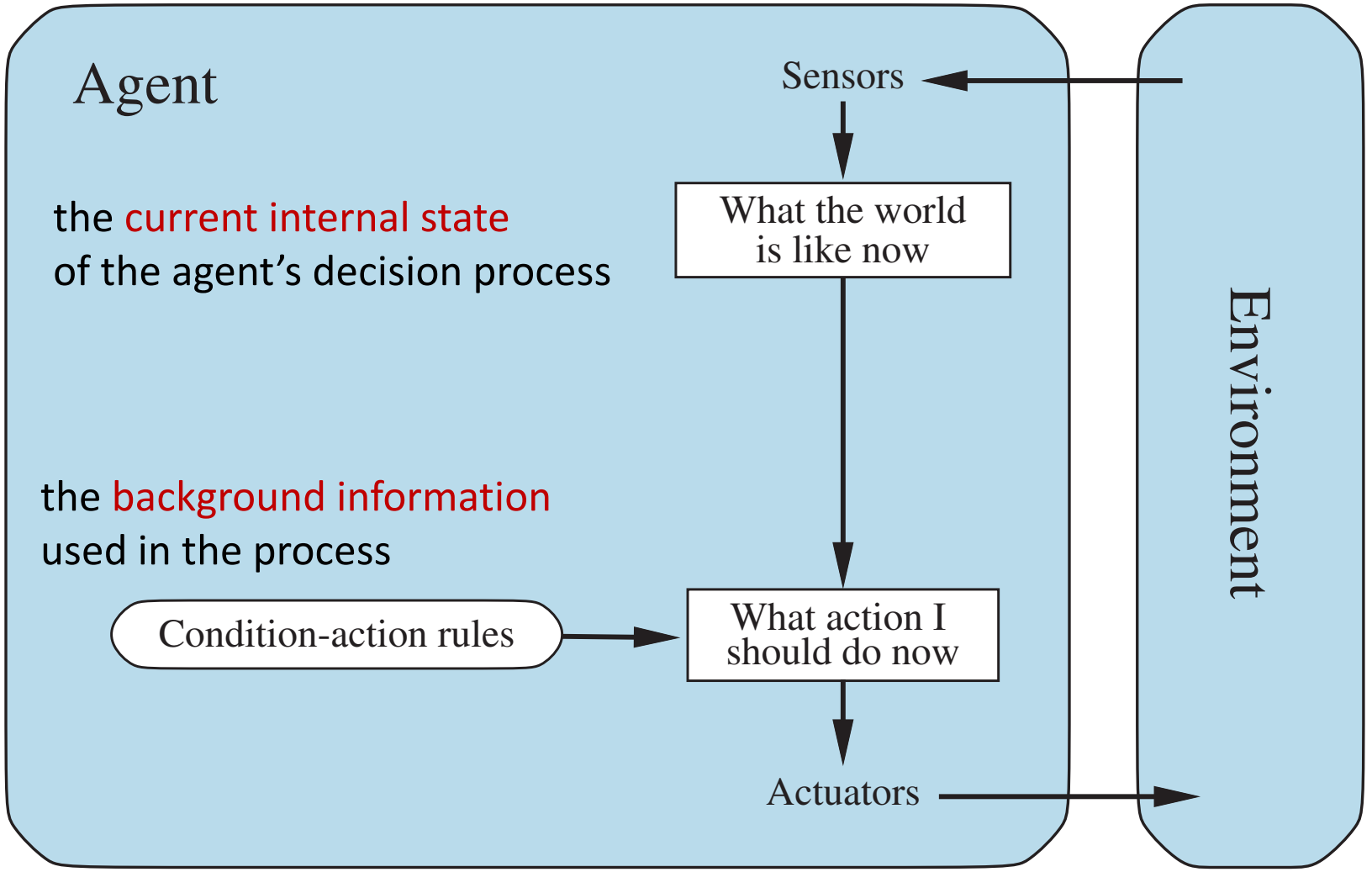
Schematic diagram of a simple reflex agent



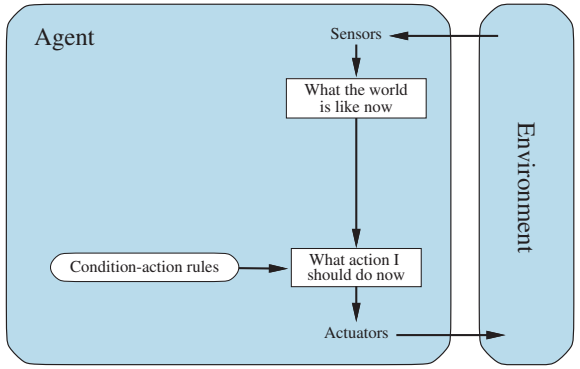
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A Simple Reflex Agent

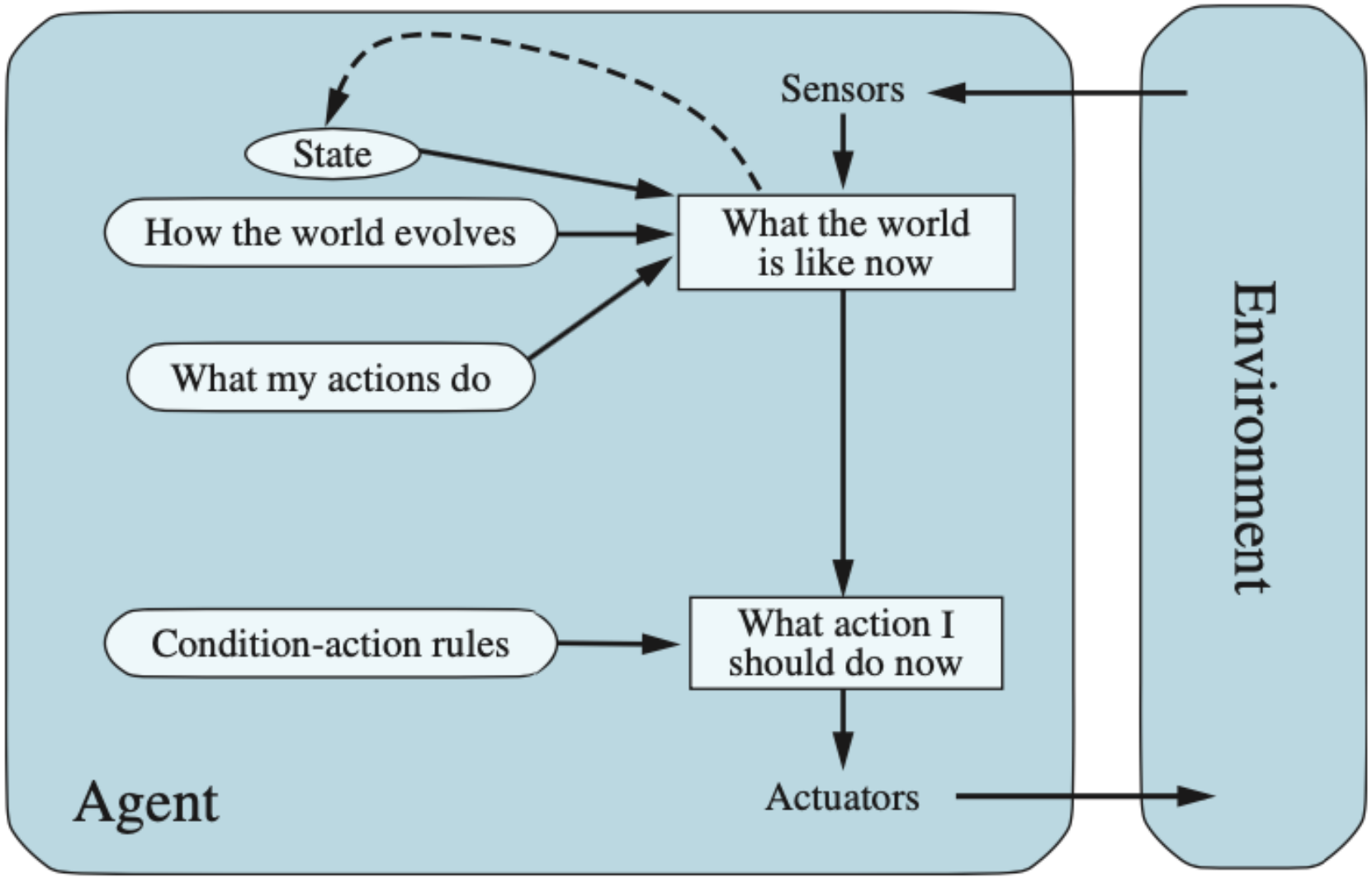
It acts according to a rule whose condition matches the current state, as defined by the percept.

function SIMPLE-REFLEX-AGENT(*percept*) **returns** an action
  persistent: *rules*, a set of condition–action rules

  state ← INTERPRET-INPUT(*percept*)
  rule ← RULE-MATCH(*state*, *rules*)
  action ← *rule*.ACTION
  return *action*



A Model-based Reflex Agent



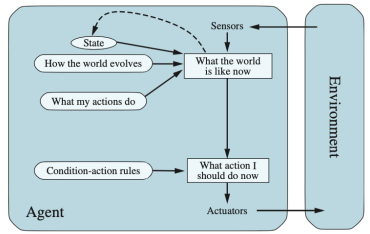
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A model-based reflex agent

It keeps track of the current state of the world,
using an internal model.
It then chooses an action in the same way as the reflex agent.

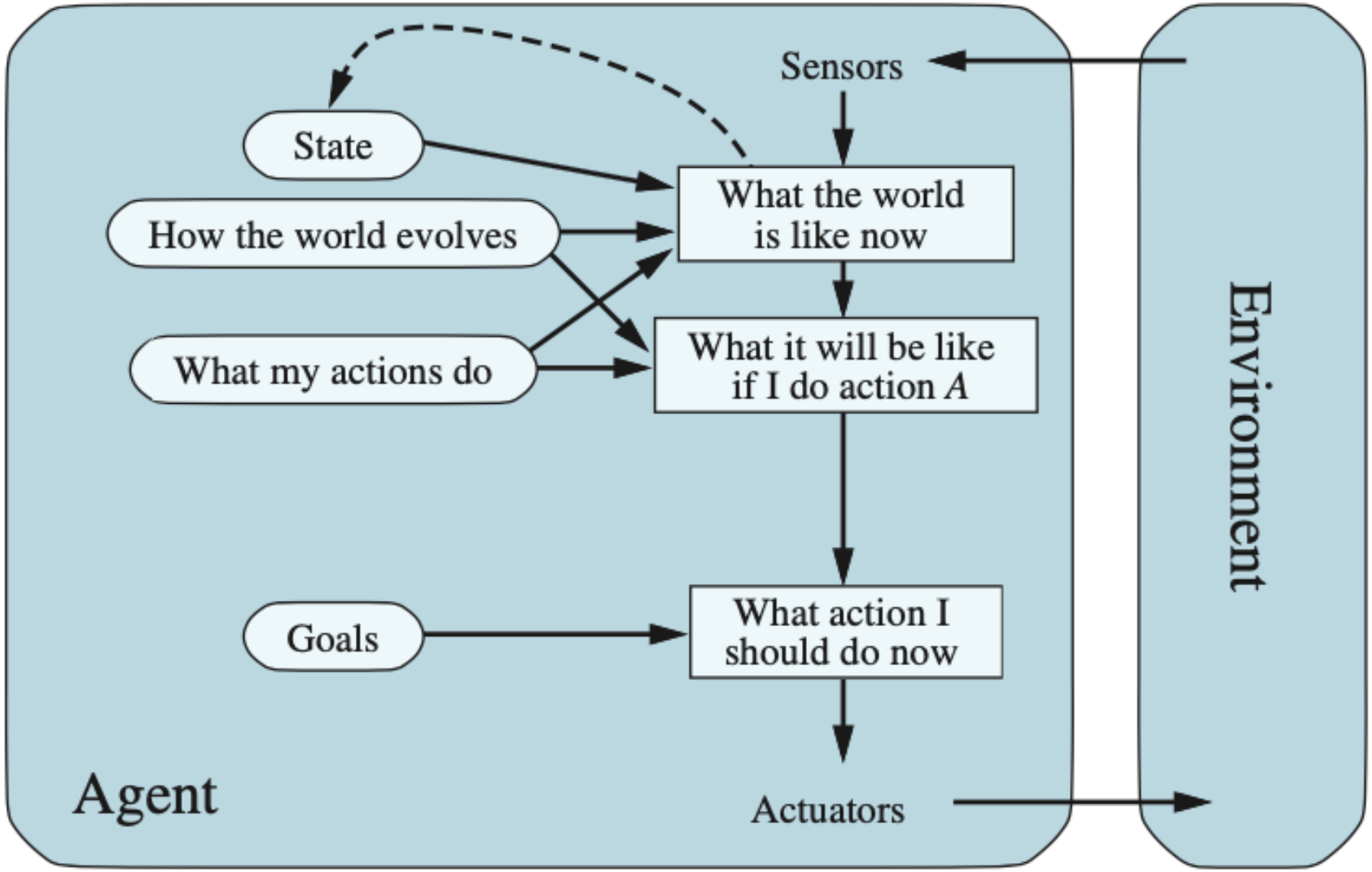
function MODEL-BASED-REFLEX-AGENT(*percept*) **returns** an action
  persistent: *state*, the agent's current conception of the world state
    transition_model, a description of how the next state depends on
      the current state and action
    sensor_model, a description of how the current world state is reflected
      in the agent's percepts
    rules, a set of condition–action rules
    action, the most recent action, initially none

state ← UPDATE-STATE(*state*, *action*, *percept*, *transition_model*, *sensor_model*)
rule ← RULE-MATCH(*state*, *rules*)
action ← *rule*.ACTION
return *action*



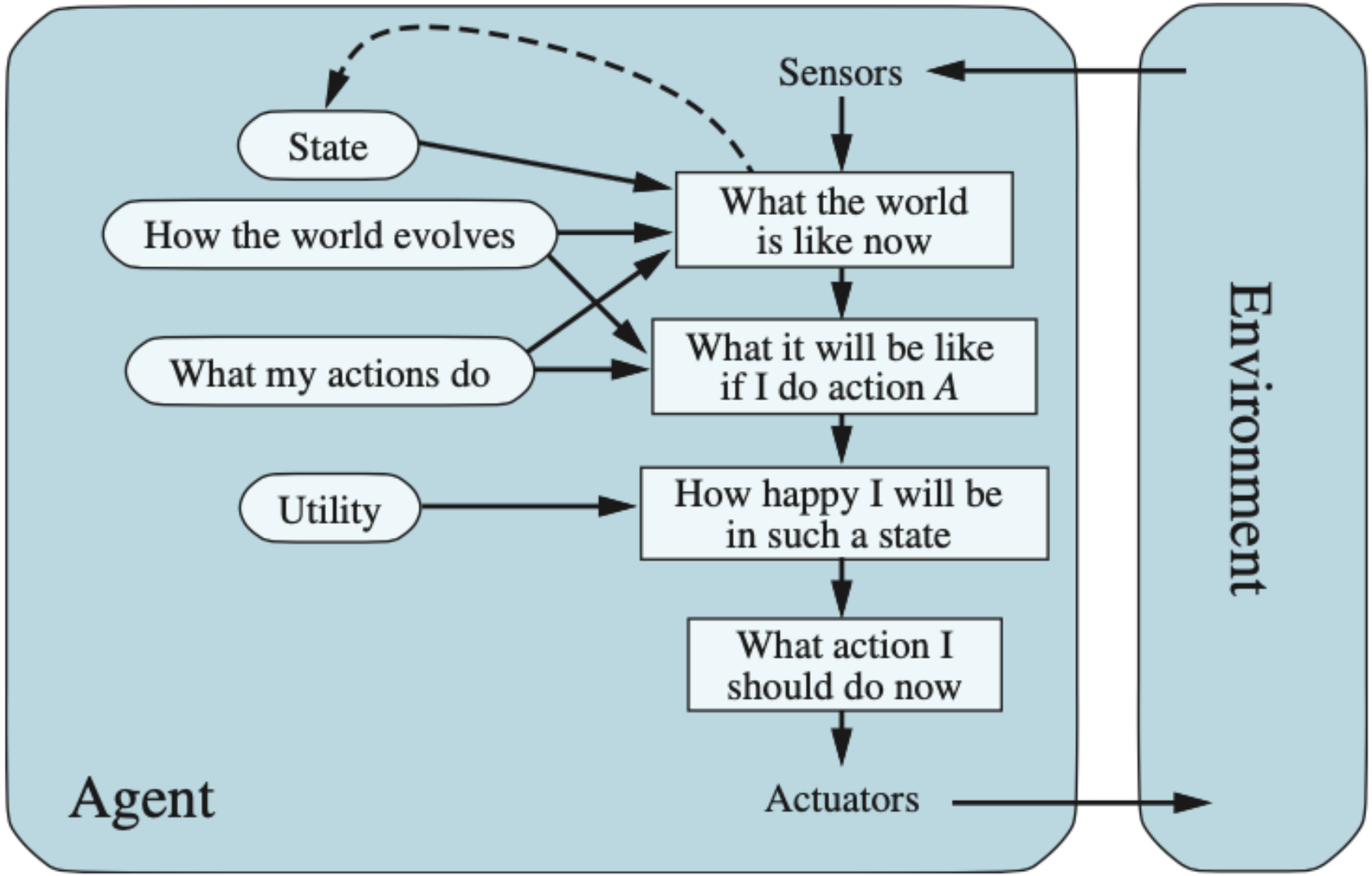
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A model-based, goal-based agent



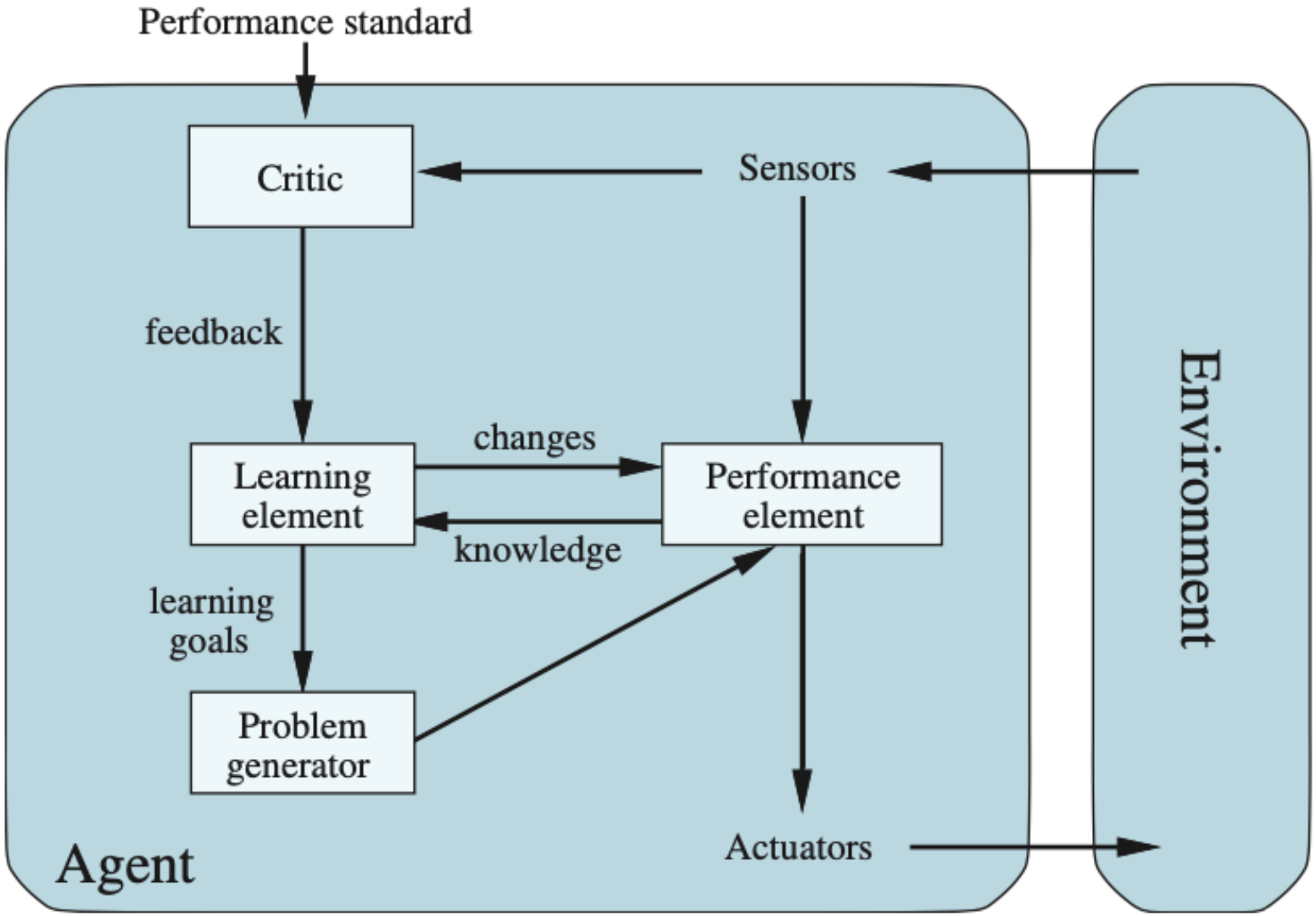
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A model-based, utility-based agent



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A general learning agent



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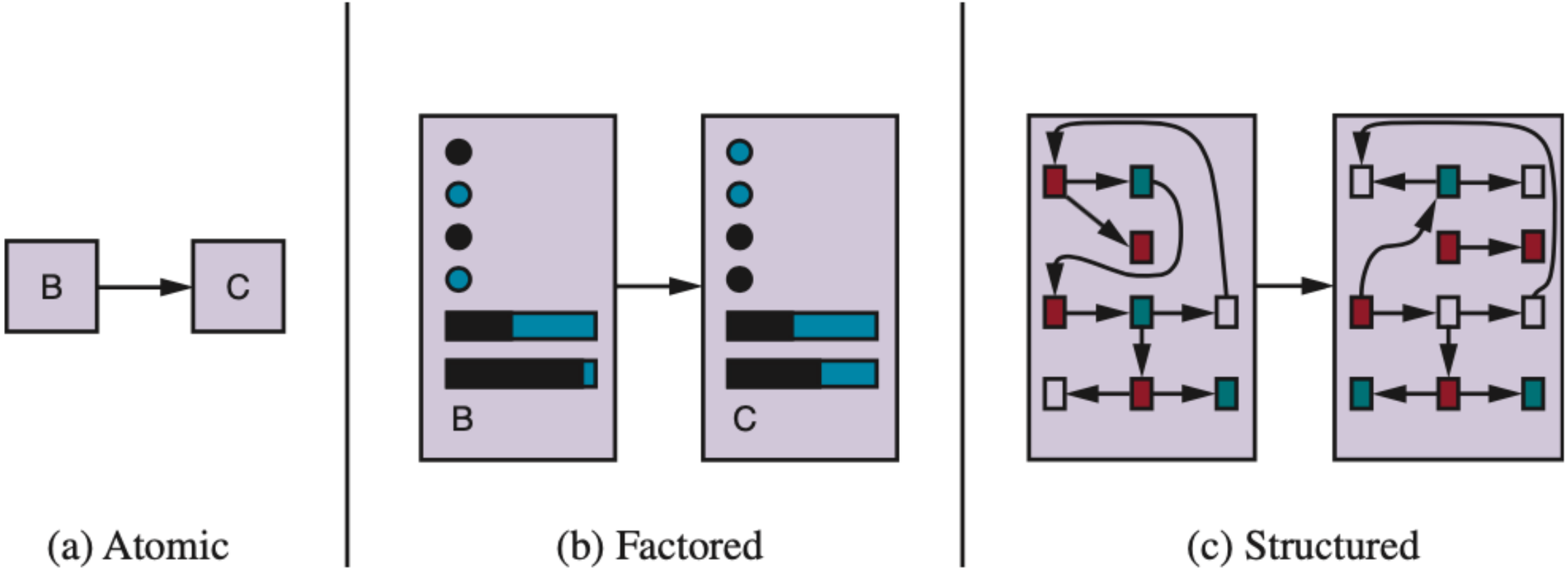
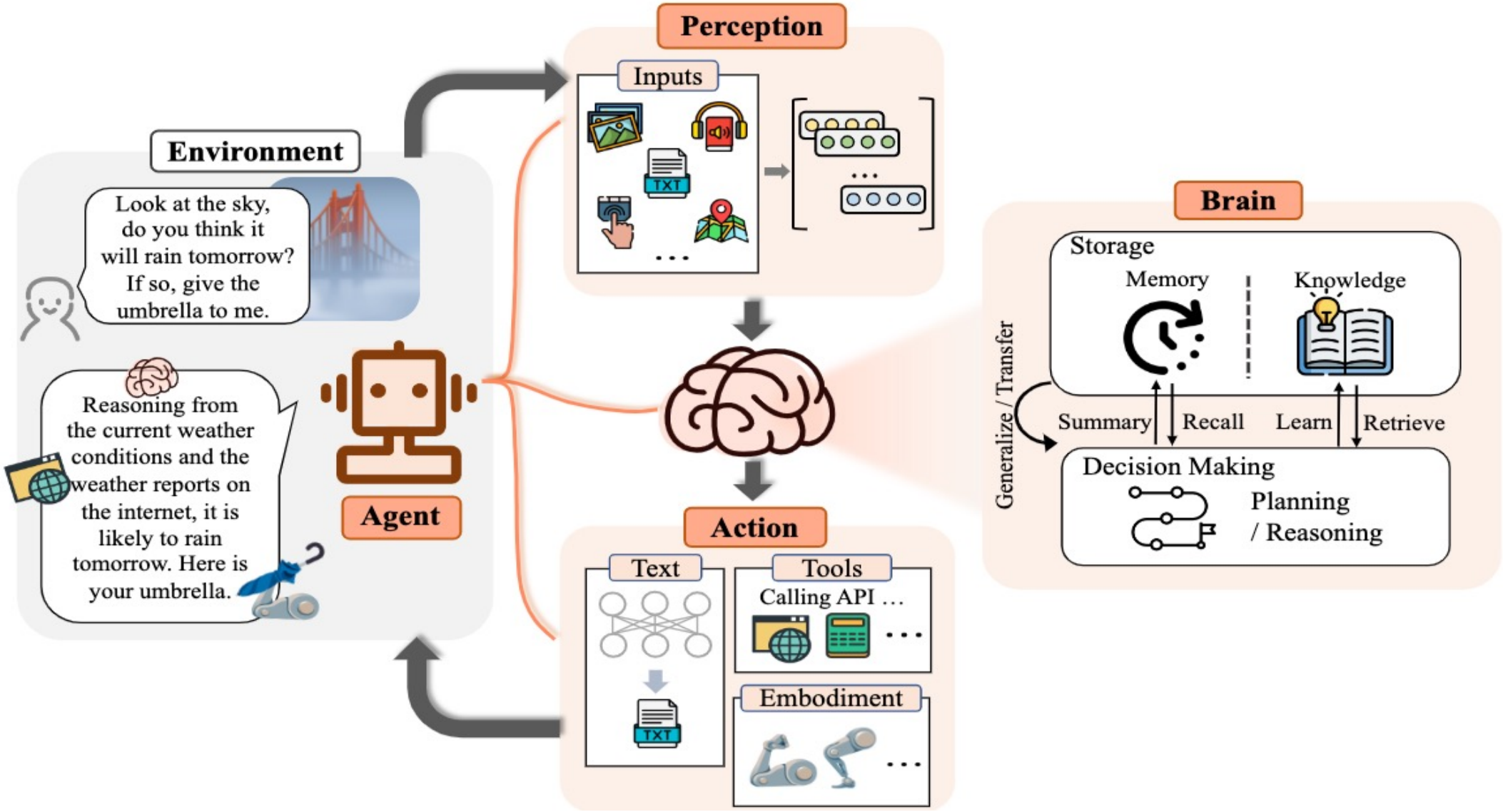
Three ways to represent states and the transitions between them



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Large Language Model (LLM) based Agents

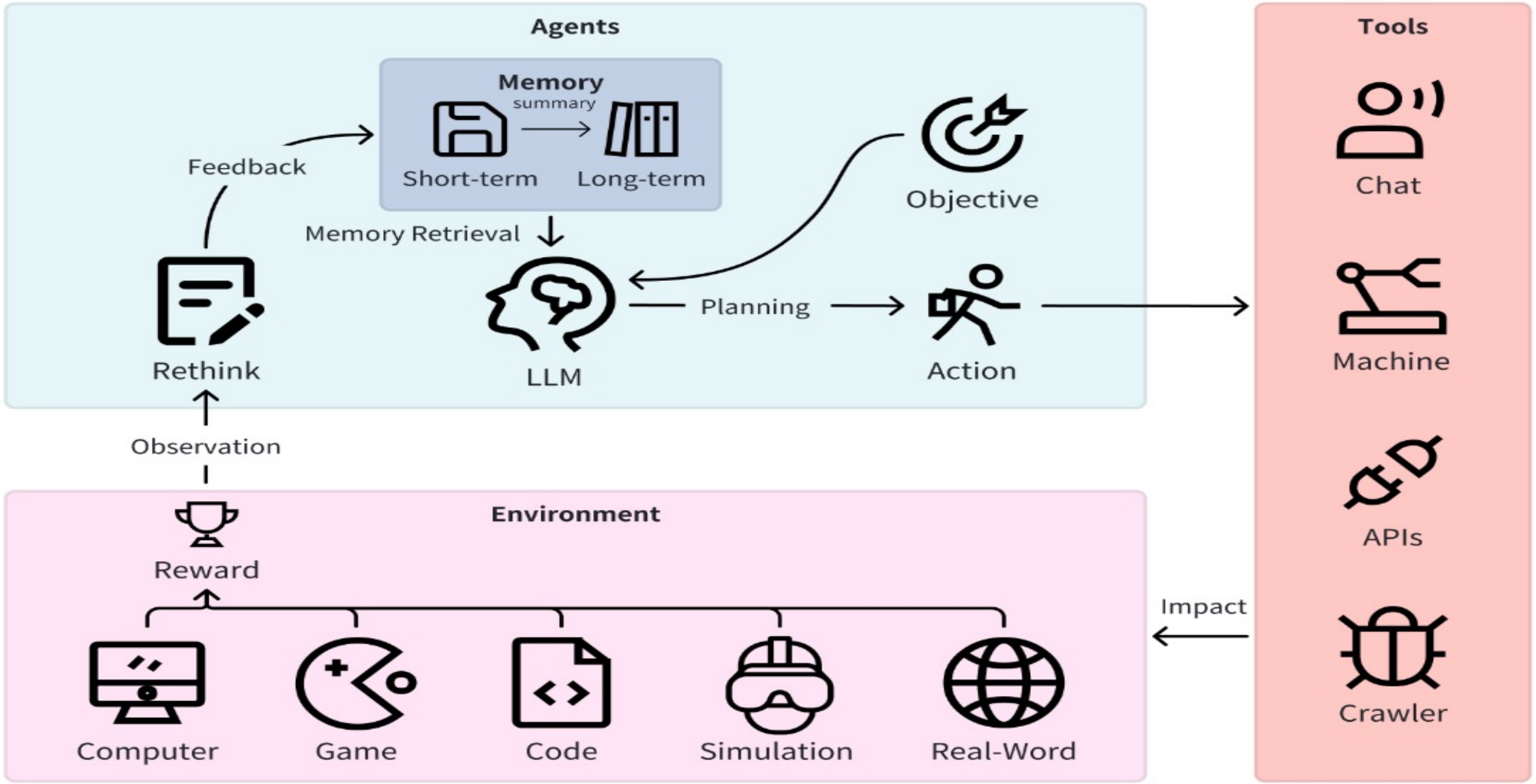


Source: Xi, Z., Chen, W., Guo, X., He, W., Ding, Y., Hong, B., ... & Gui, T. (2023). The rise and potential of large language model based agents: A survey. arXiv preprint arXiv:2309.07864.

LLM-based Agents

- **Definition: AI agents that use Large Language Models as their core decision-making mechanism**
- **Key Features:**
  - **Natural language interface**
  - **Vast knowledge base**
  - **Ability to understand context and nuance**
  - **Generalize to new tasks with minimal additional training**

LLM-based Agents



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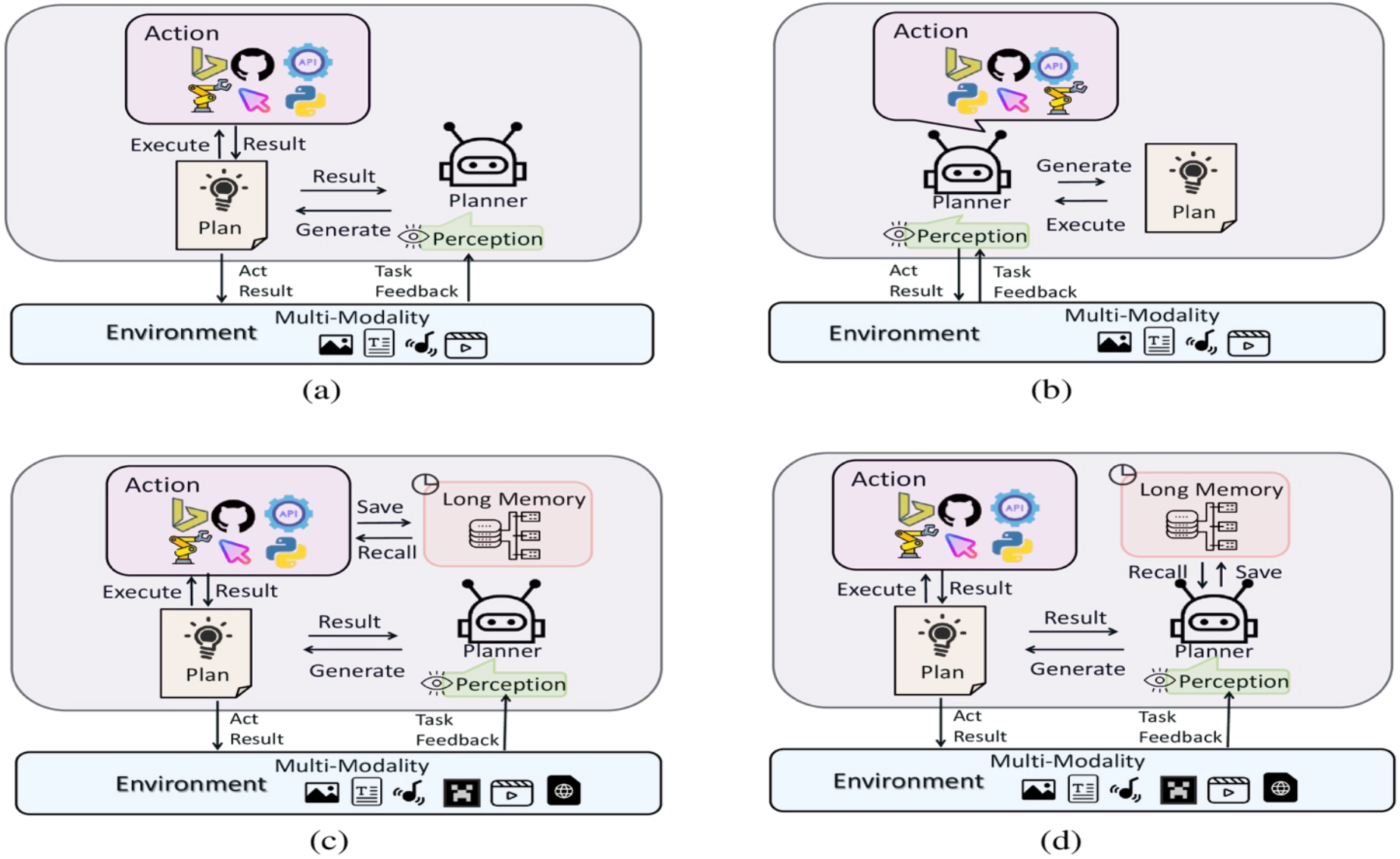
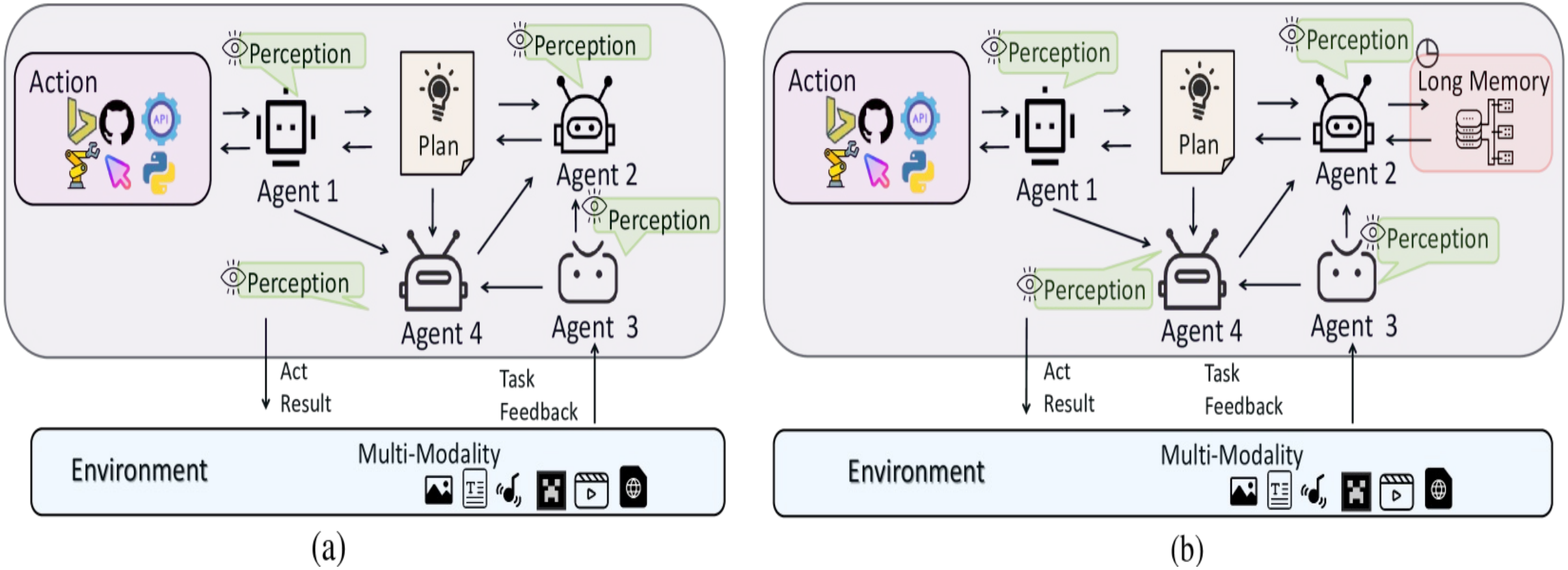
Large Multimodal Agents (LMA)



Source: Xie, J., Chen, Z., Zhang, R., Wan, X., & Li, G. (2024). Large Multimodal Agents: A Survey. ArXiv, abs/2402.15116.

Large Multimodal Agents (LMA)



Source: Xie, J., Chen, Z., Zhang, R., Wan, X., & Li, G. (2024). Large Multimodal Agents: A Survey. ArXiv, abs/2402.15116.

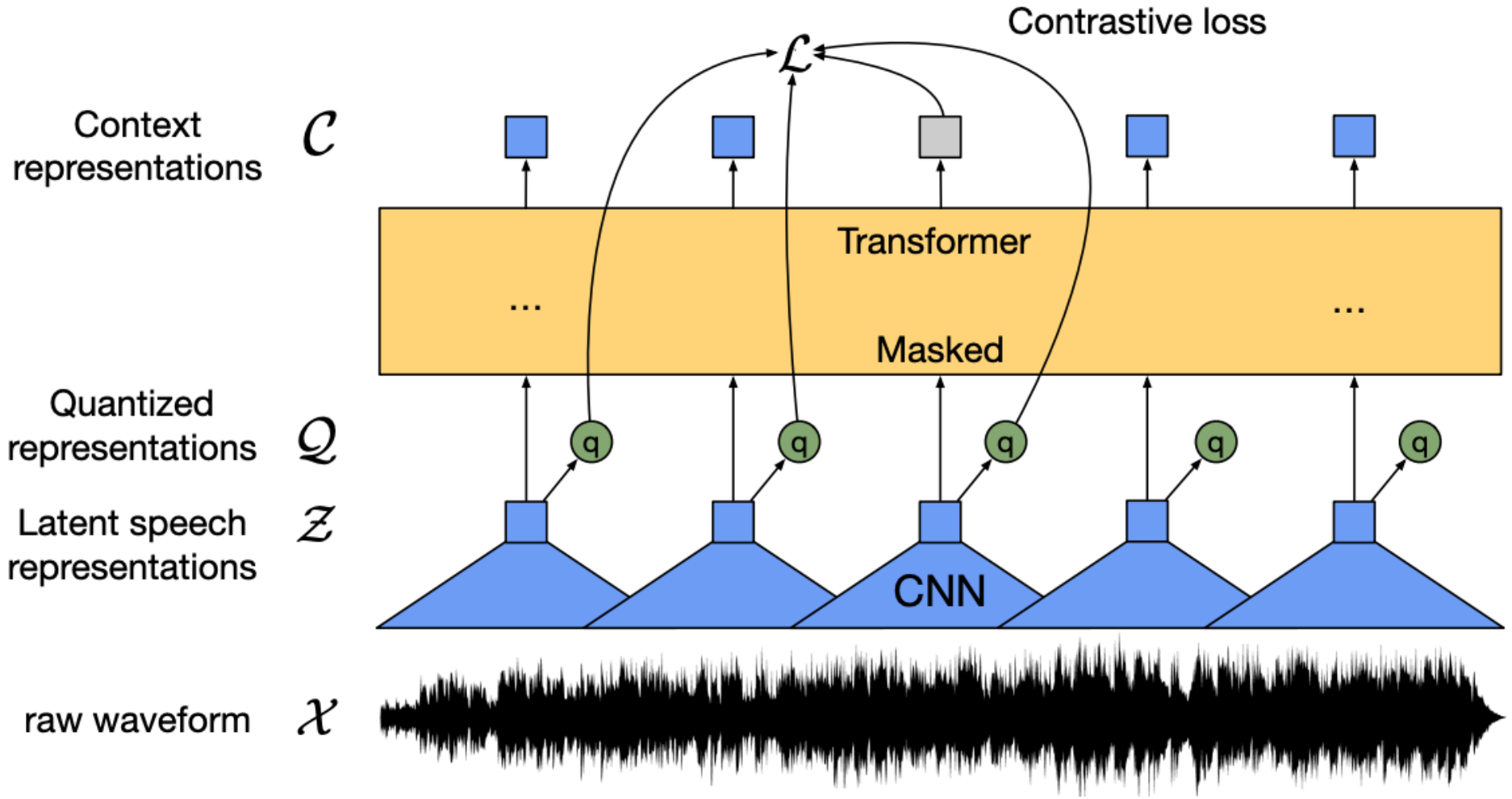
Artificial Intelligence:

6. Communicating, Perceiving, and Acting

- Natural Language Processing
- Deep Learning for Natural Language Processing
- Computer Vision
- Robotics

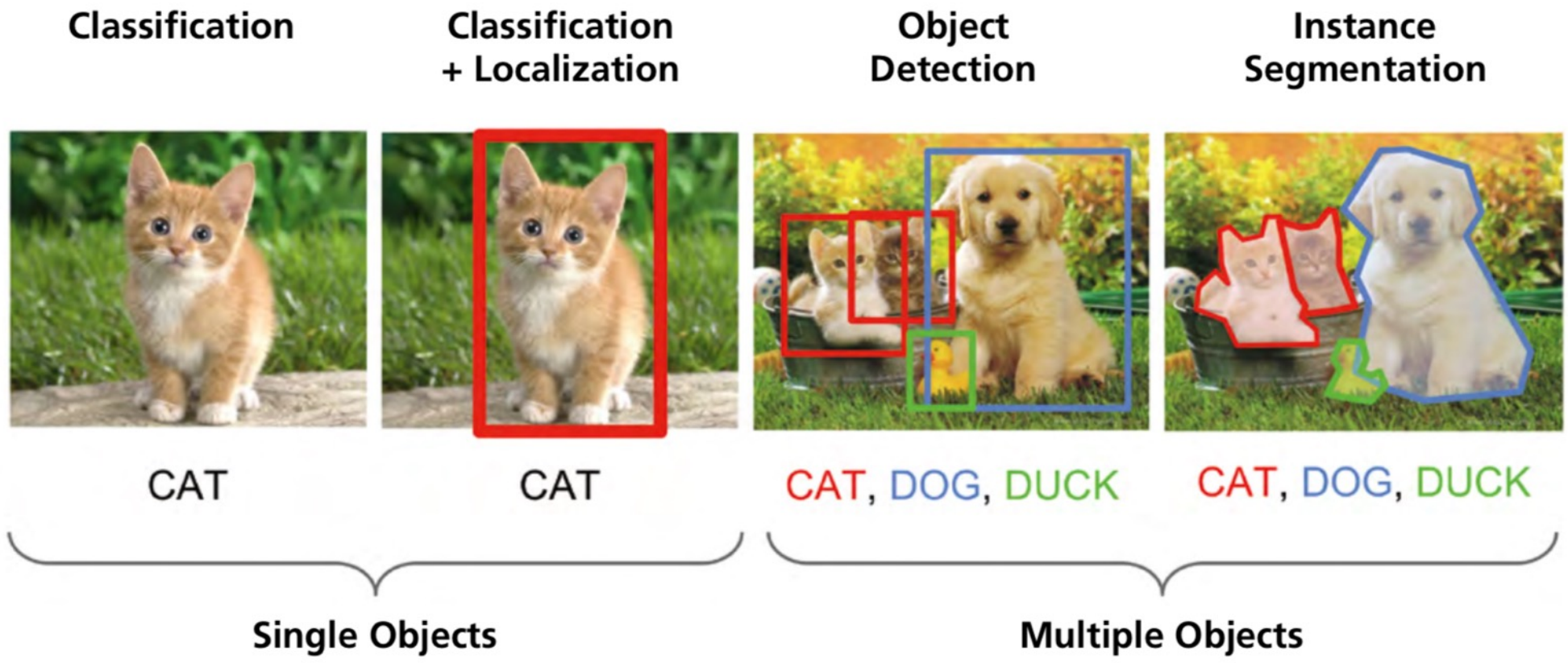
wav2vec 2.0:

A framework for self-supervised learning of speech representations



Source: Baevski, Alexei, Yuhao Zhou, Abdelrahman Mohamed, and Michael Auli.
"wav2vec 2.0: A framework for self-supervised learning of speech representations." Advances in Neural Information Processing Systems 33 (2020): 12449-12460.

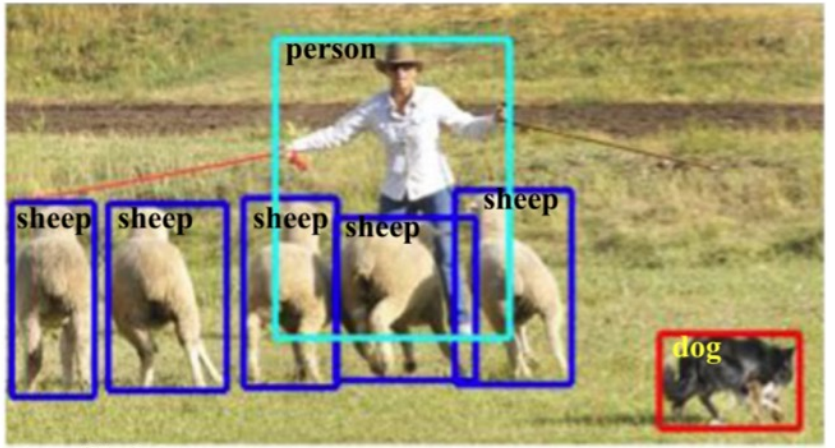
Computer Vision:
Image Classification, Object Detection, Object Instance Segmentation



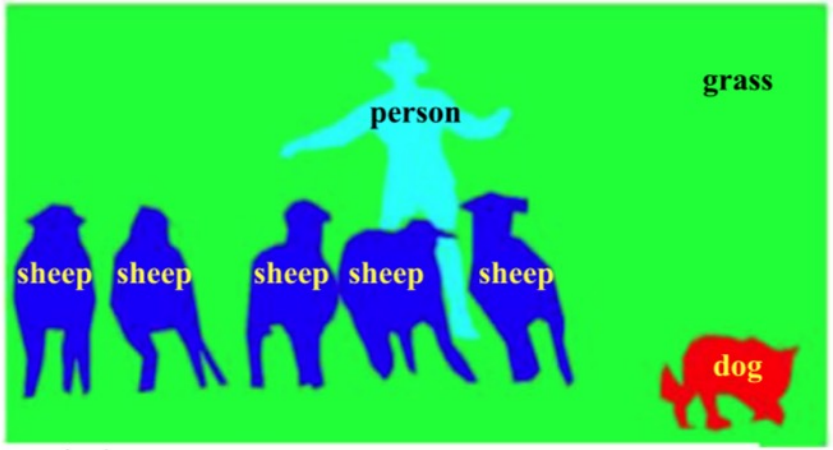
Source: DHL (2018), Artificial Intelligence in Logistics, http://www.globalhha.com/doclib/data/upload/doc_con/5e50c53c5bf67.pdf/

Computer Vision: Object Detection

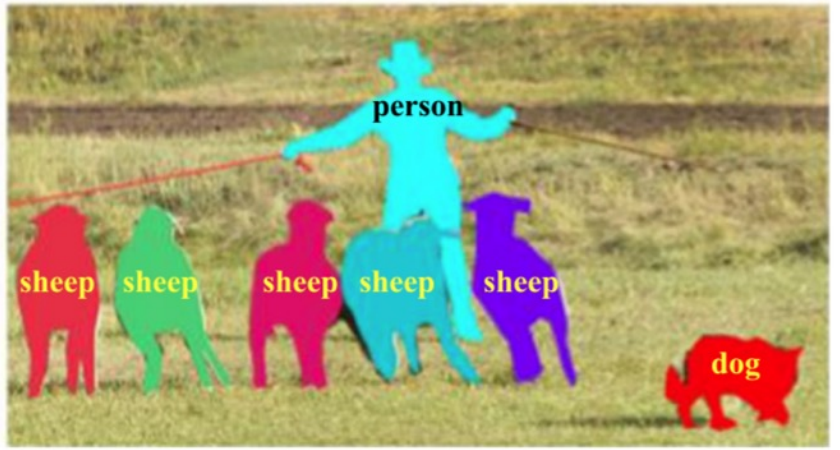
(a) Object Classification



(b) Generic Object Detection (Bounding Box)



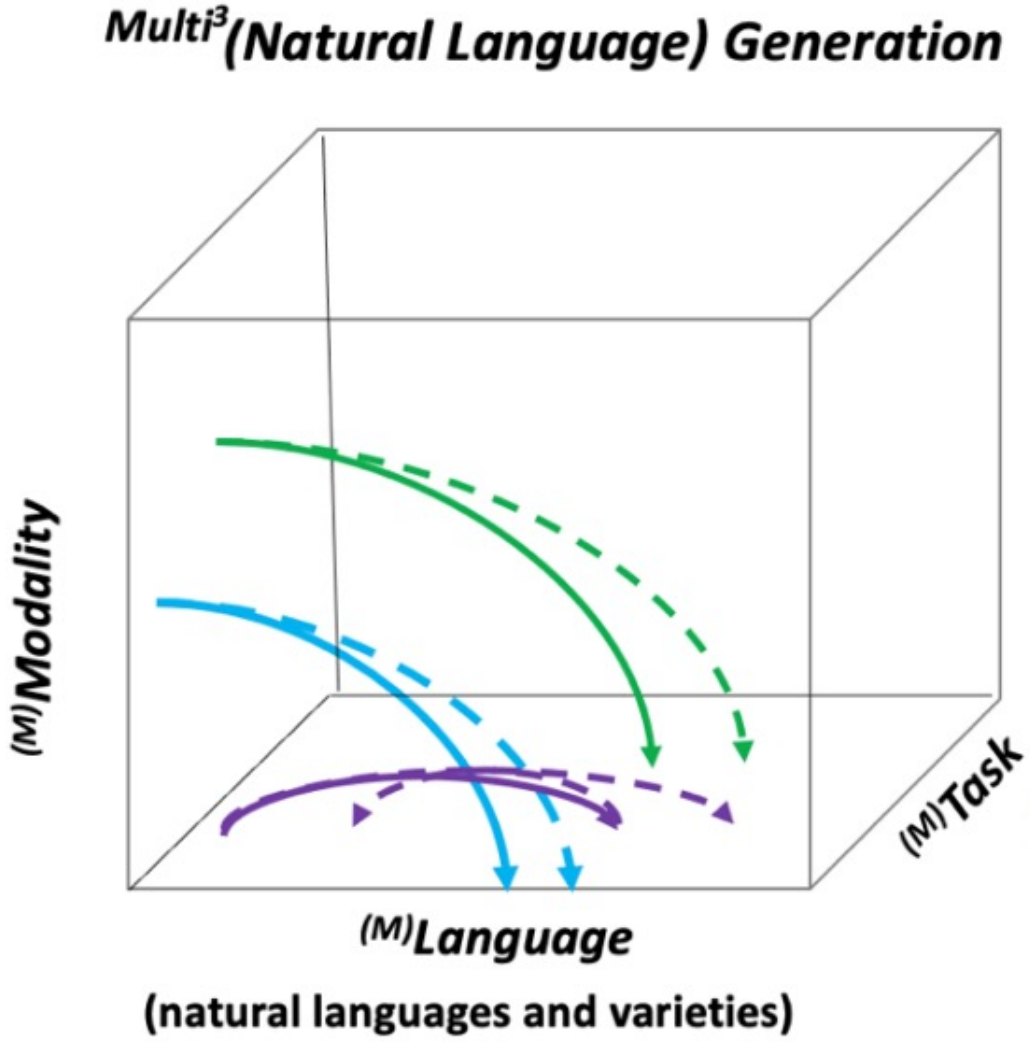
(c) Semantic Segmentation



(d) Object Instance Segmetation

Source: Li Liu, Wanli Ouyang, Xiaogang Wang, Paul Fieguth, Jie Chen, Xinwang Liu, and Matti Pietikäinen. "Deep learning for generic object detection: A survey." International journal of computer vision 128, no. 2 (2020): 261-318.

NLG from a Multilingual, Multimodal and Multi-task perspective

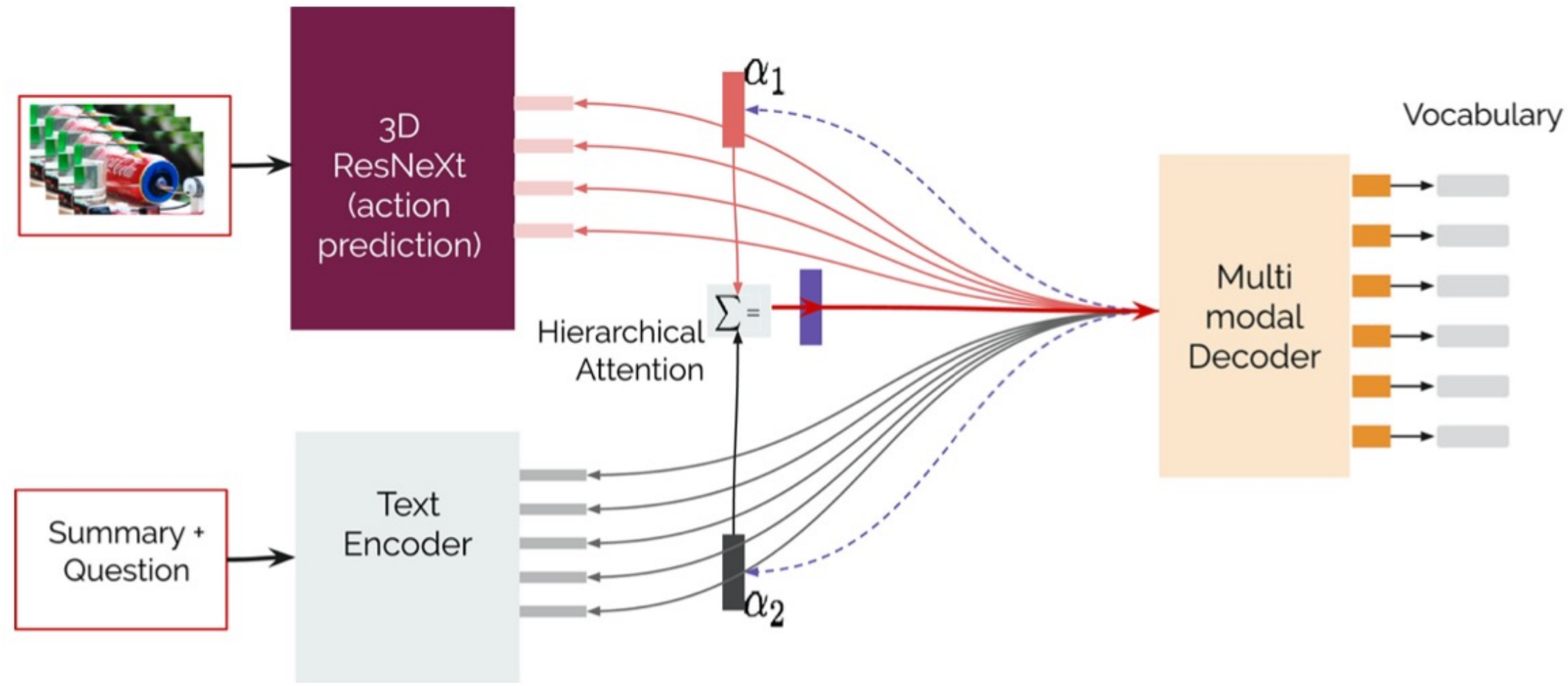


- Text
- Speech
- Vision

- Recognize and transcribe speech (ASR)
- Translate from one language to another (MT)
- Describe, ask or answer questions or converse about visual objects (Captioning, VQA, Visual Dialogue, …)

Source: Erdem, Erkut, Menekse Kuyu, Semih Yagcioglu, Anette Frank, Letitia Parcalabescu, Barbara Plank, Andrii Babii et al. "Neural Natural Language Generation: A Survey on Multilinguality, Multimodality, Controllability and Learning." Journal of Artificial Intelligence Research 73 (2022): 1131-1207.

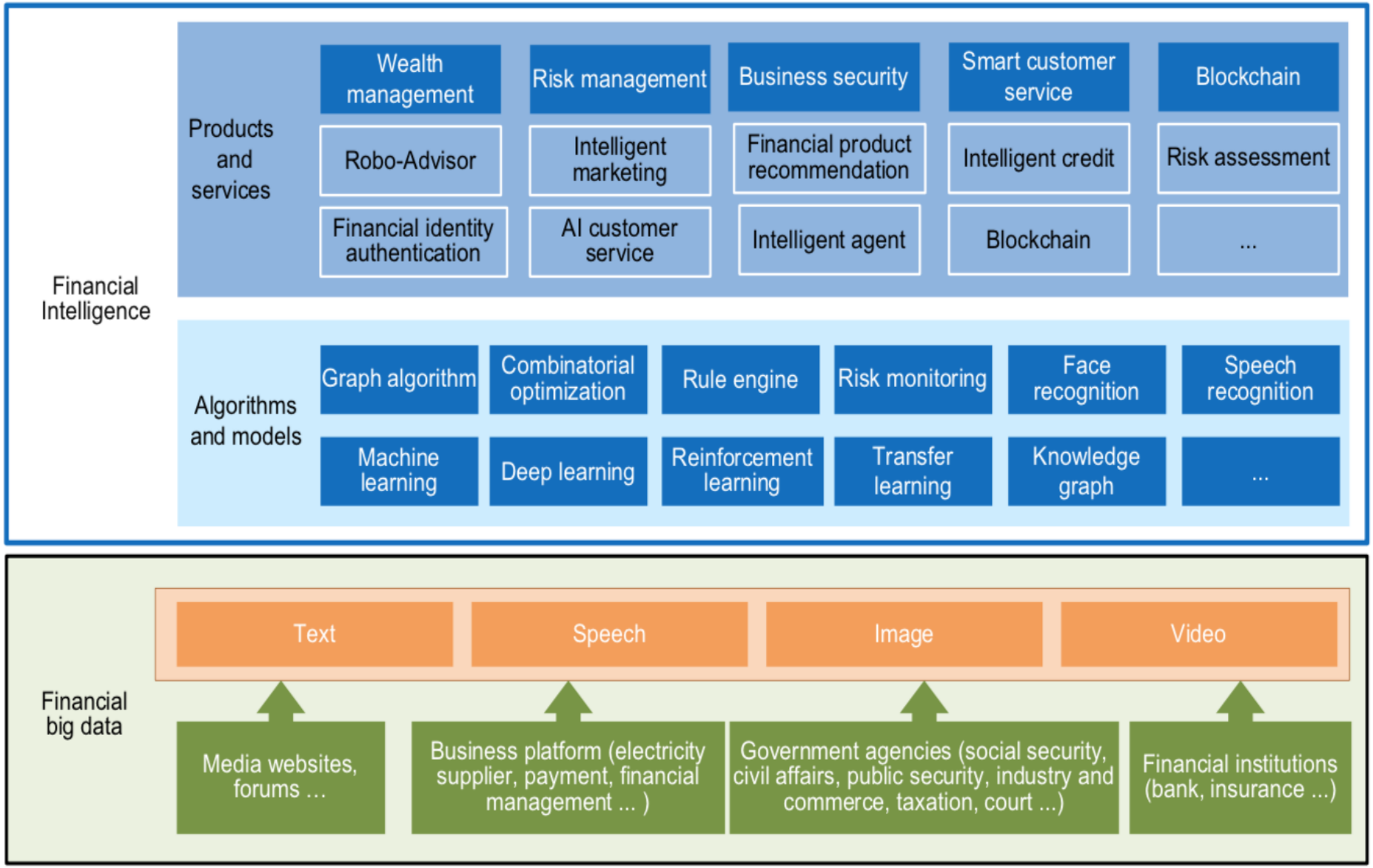
Text-and-Video Dialog Generation Models with Hierarchical Attention



Source: Erdem, Erkut, Menekse Kuyu, Semih Yagcioglu, Anette Frank, Letitia Parcalabescu, Barbara Plank, Andrii Babii et al. "Neural Natural Language Generation: A Survey on Multilinguality, Multimodality, Controllability and Learning." Journal of Artificial Intelligence Research 73 (2022): 1131-1207.

FinBrain: when Finance meets AI 2.0

(Zheng et al., 2019)



Source: Xiao-lin Zheng, Meng-ying Zhu, Qi-bing Li, Chao-chao Chen, and Yan-chao Tan (2019), "Finbrain: When finance meets AI 2.0." Frontiers of Information Technology & Electronic Engineering 20, no. 7, pp. 914-924

Technology-driven Financial Industry Development

Development stage	Driving technology	Main landscape	Inclusive finance	Relationship between technology and finance
Fintech 1.0 (financial IT)	Computer	Credit card, ATM, and CRMS	Low	Technology as a tool
Fintech 2.0 (Internet finance)	Mobile Internet	Marketplace lending, third-party payment, crowdfunding, and Internet insurance	Medium	Technology-driven change
Fintech 3.0 (financial intelligence)	AI, Big Data, Cloud Computing, Blockchain	Intelligent finance	High	Deep fusion

Source: Xiao-lin Zheng, Meng-ying Zhu, Qi-bing Li, Chao-chao Chen, and Yan-chao Tan (2019), "Finbrain: When finance meets AI 2.0." Frontiers of Information Technology & Electronic Engineering 20, no. 7, pp. 914-924

Deep learning for financial applications: A survey

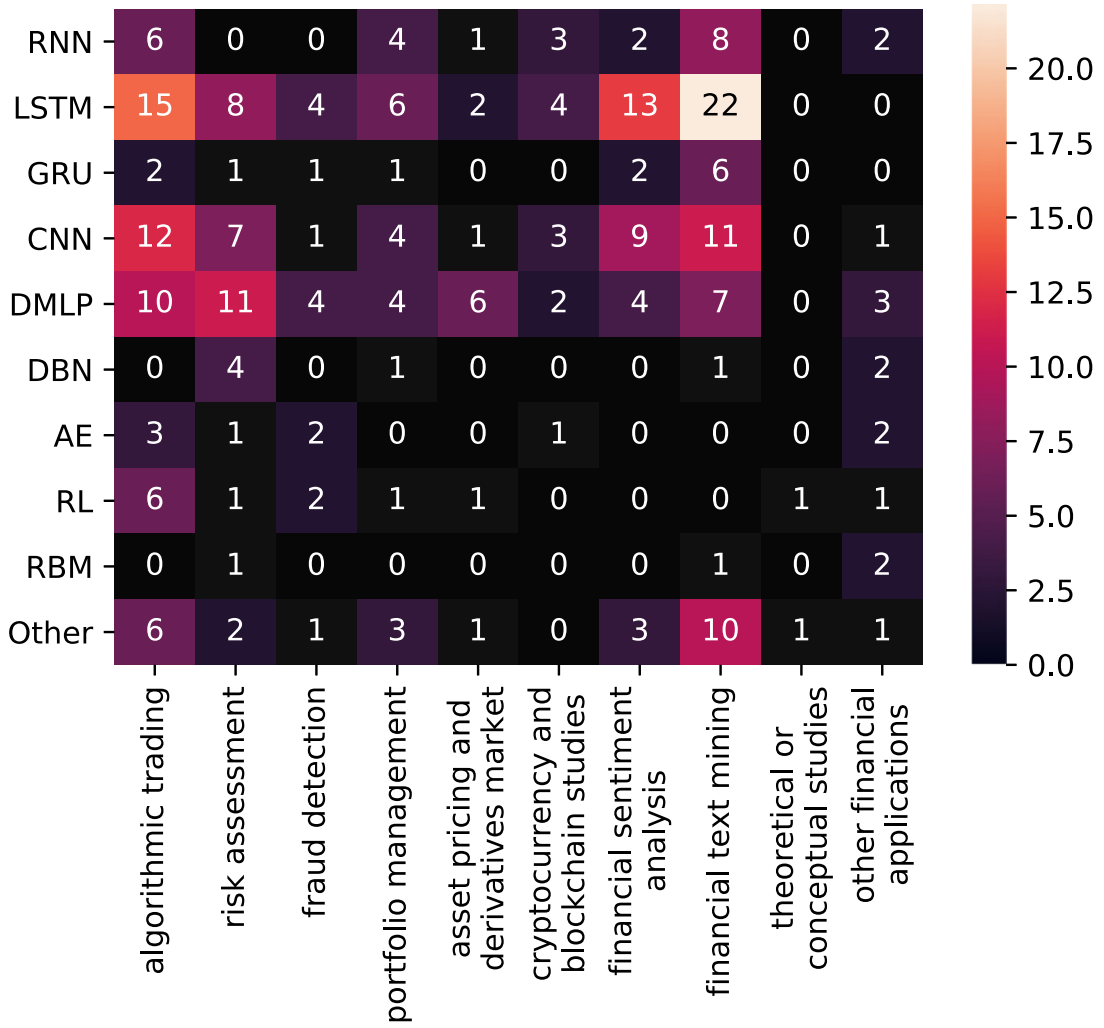
Applied Soft Computing (2020)

Source:
Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey."
Applied Soft Computing (2020): 106384.

Financial time series forecasting with deep learning: A systematic literature review: 2005–2019 Applied Soft Computing (2020)

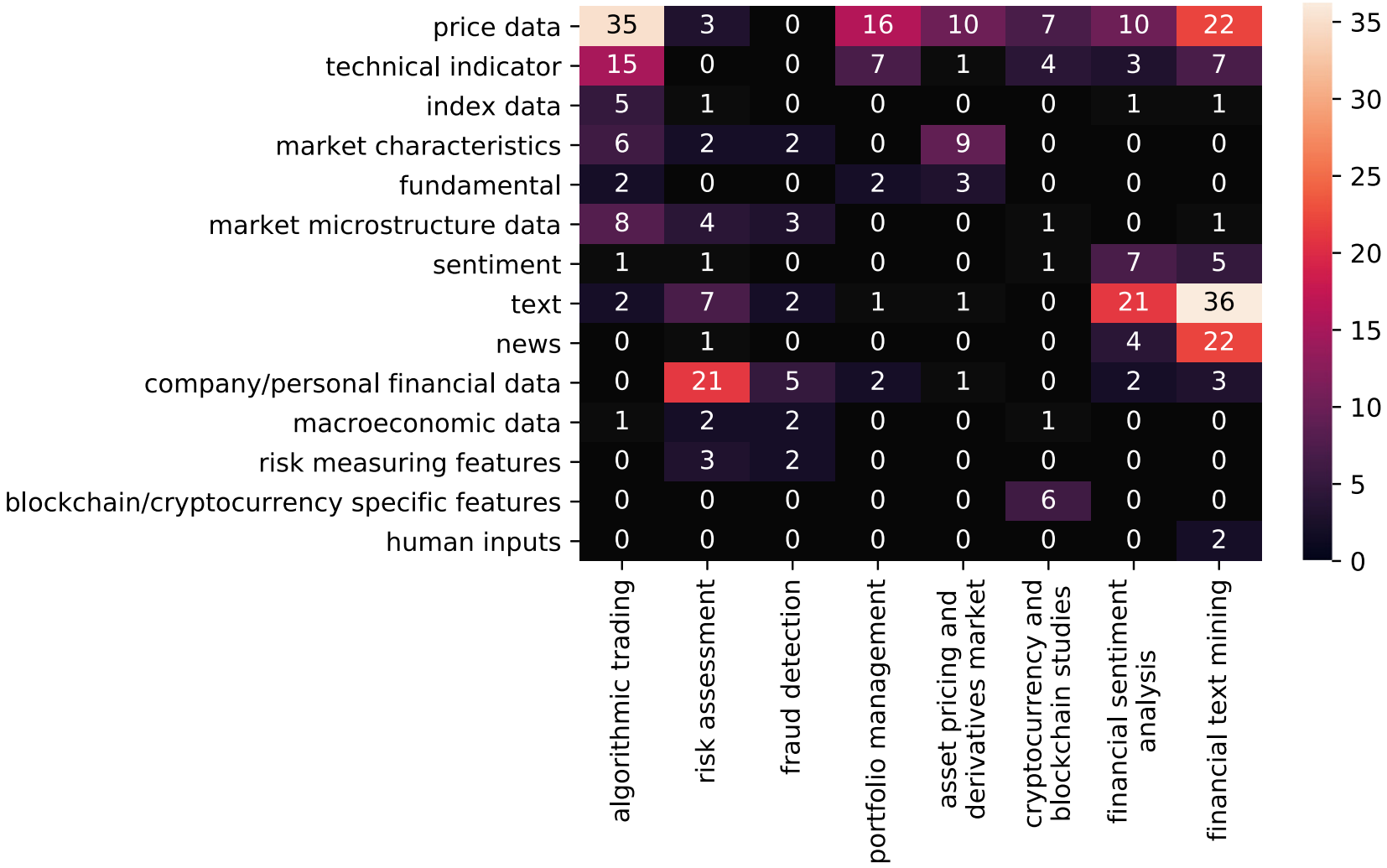
Source:
Omer Berat Sezer, Mehmet Ugur Gudelek, and Ahmet Murat Ozbayoglu (2020), "Financial time series forecasting with deep learning: A systematic literature review: 2005–2019." Applied Soft Computing 90 (2020): 106181.

Deep learning for financial applications: Topic-Model Heatmap



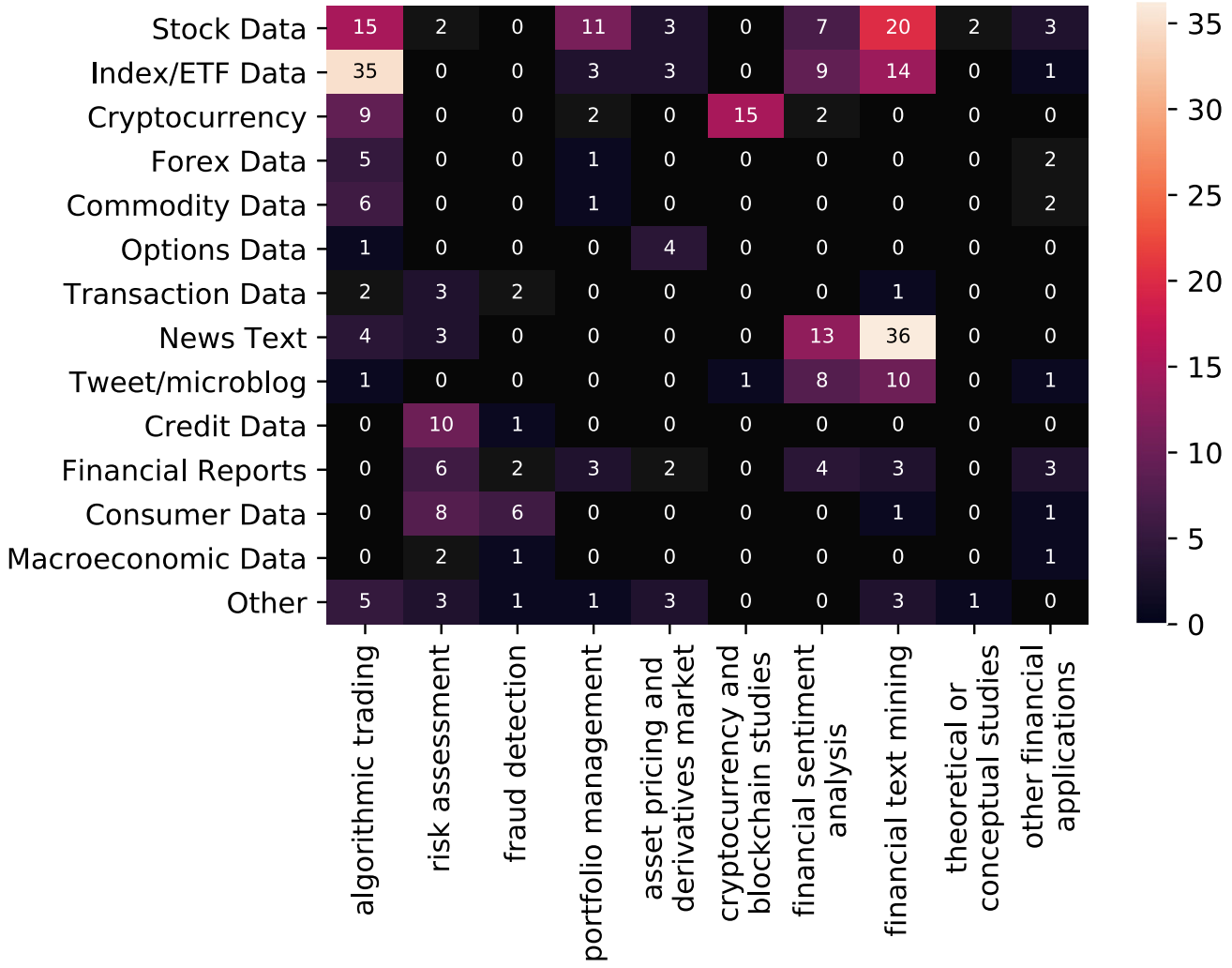
Source: Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.

Deep learning for financial applications: Topic-Feature Heatmap



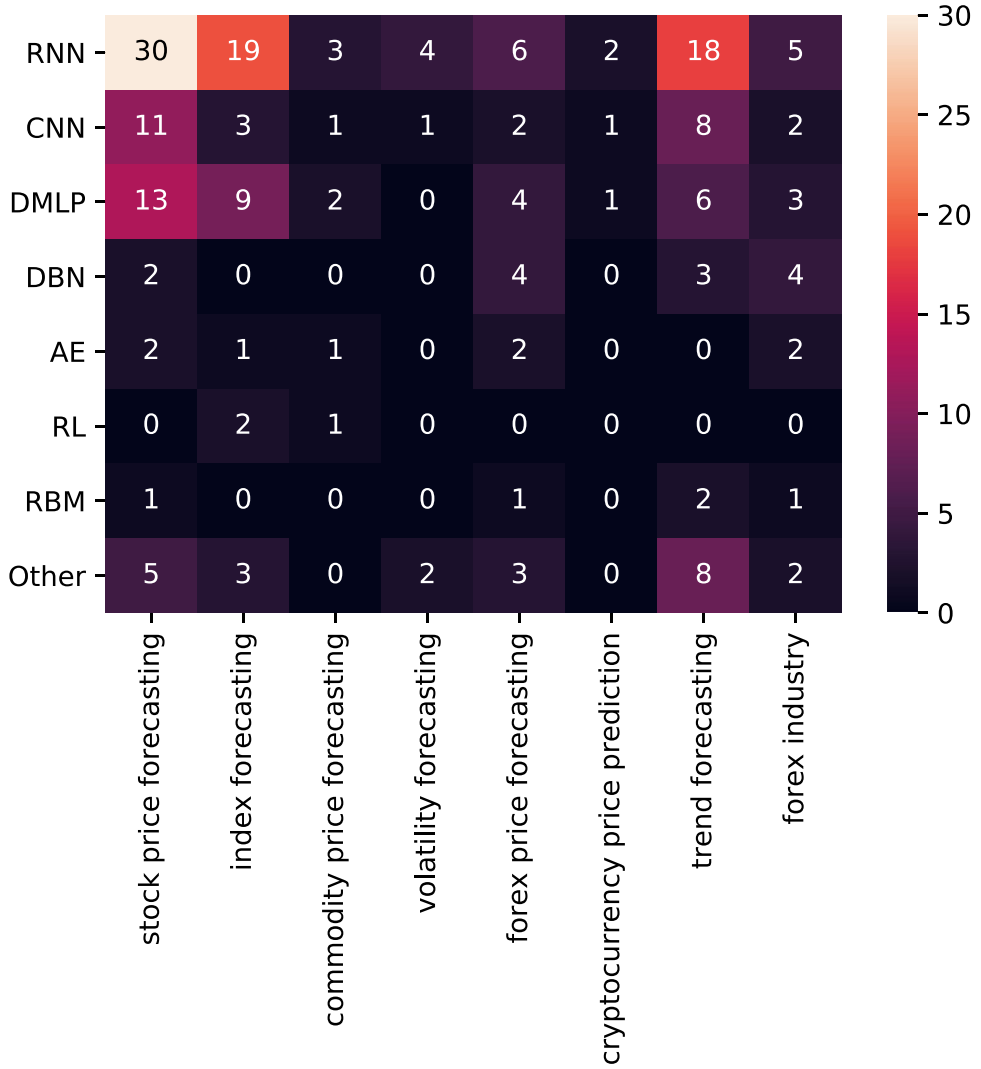
Source: Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.

Deep learning for financial applications: Topic-Dataset Heatmap



Source: Ahmet Murat Ozbayoglu, Mehmet Ugur Gudelek, and Omer Berat Sezer (2020). "Deep learning for financial applications: A survey." Applied Soft Computing (2020): 106384.

Financial time series forecasting with deep learning: Topic-model heatmap



Source: Omer Berat Sezer, Mehmet Ugur Gudelek, and Ahmet Murat Ozbayoglu (2020), "Financial time series forecasting with deep learning: A systematic literature review: 2005–2019." Applied Soft Computing 90 (2020): 106181.

Artificial Intelligence
Problem Solving

Artificial Intelligence: A Modern Approach

1. Artificial Intelligence
2. Problem Solving
3. Knowledge and Reasoning
4. Uncertain Knowledge and Reasoning
5. Machine Learning
6. Communicating, Perceiving, and Acting
7. Philosophy and Ethics of AI

Artificial Intelligence:
2. Problem Solving

- Solving Problems by Searching
- Search in Complex Environments
- Adversarial Search and Games
- Constraint Satisfaction Problems

LLM-enhanced Problem Solving

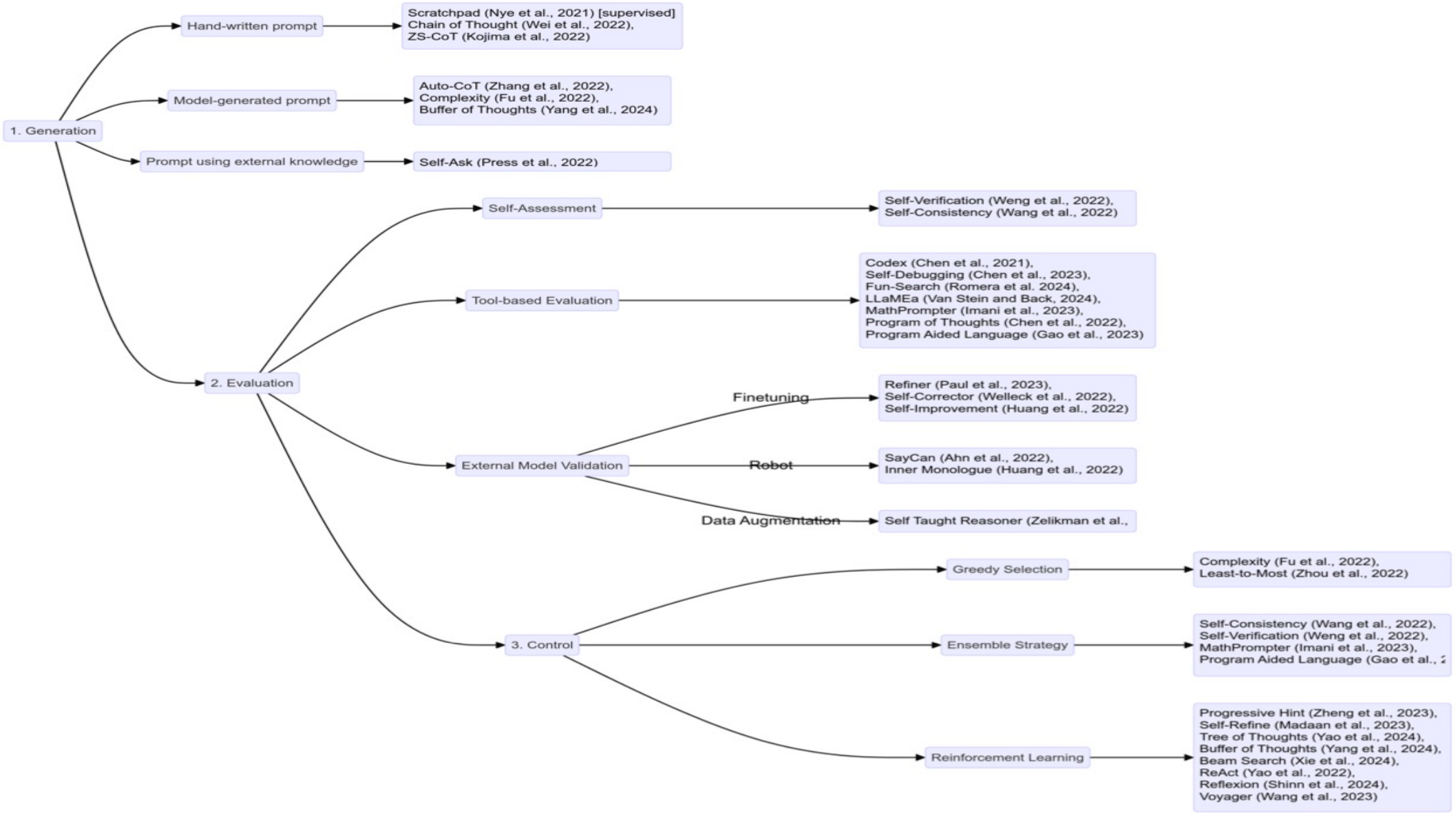
Problem Solving and LLM-enhanced Techniques

- Traditional Search Algorithms
  - Breadth-first Search (BFS)
  - Depth-first Search (DFS)
  - A* Search
- LLM-enhanced Problem Solving
  - Chain-of-thought (CoT) prompting
  - Few-shot learning for problem decomposition
  - Integration with external tools and APIs

LLM-based Agents for Complex Problem Solving

- ReAct: Reasoning and Acting in Language Models
- MRKL (Modular Reasoning, Knowledge and Language) systems
- LLM-powered planning and decision making
- Chain-of-thought Prompting
  - Solving a complex problem
    using chain-of-thought prompting

LLM-Reasoning Approaches: Prompt Generation, Evaluation, and Control



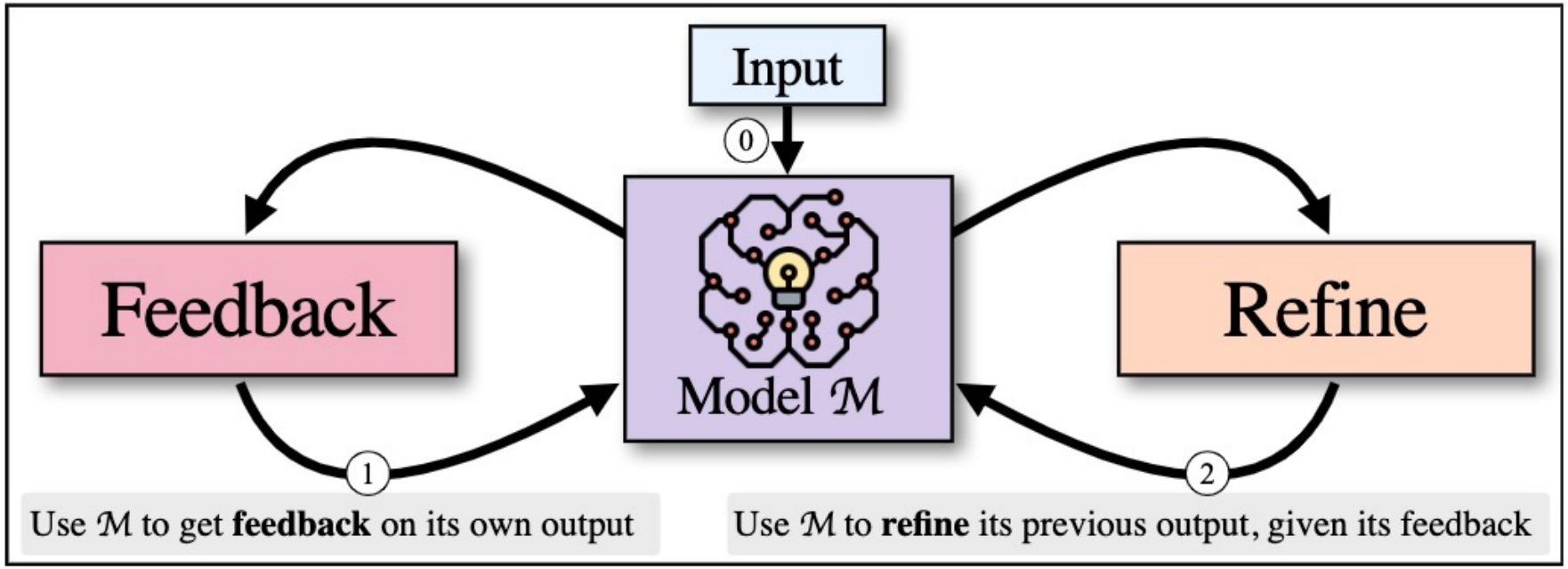
Source: Plaat, A., Wong, A., Verberne, S., Broekens, J., van Stein, N., & Back, T. (2024). Reasoning with Large Language Models, a Survey. arXiv preprint arXiv:2407.11511.

LLM-Reasoning Approaches: Prompt Generation, Evaluation, and Control

Approach	Domain	Step generation	Step evaluation	Step control
Scratchpad [Nye et al., 2021]	math word	**hand-wr/supervised**	-	greedy/1prompt
Chain-of-thought [Wei et al., 2022b]	math word	**hand-written**	-	greedy/1prompt
ZS-CoT [Kojima et al., 2022]	math word	**hand-written**	-	greedy/1prompt
Auto-CoT [Zhang et al., 2022]	math word	**model-generated**	-	clustering
Complexity [Fu et al., 2022]	math word	**hand-written**	self-consistency	greedy/1prompt
Self-ask [Press et al., 2022]	math word	**external knowledge**	LLM	multi-hop questions
Self-verification [Weng et al., 2022]	math word	hand-written	**back-verify**	ensemble
Self-consistency [Wang et al., 2022b]	math word	hand-written	**majority**	ensemble
Codex [Chen et al., 2021]	code	-	**tool-based**	-
Self-debugging [Chen et al., 2023]	code	hand-written	**tool-based**	greedy
Fun-search [Romera-Paredes et al., 2024]	code	hand-written	**tool-based**	evolutionary algorithm
LLaMEa [van Stein and Bäck, 2024]	code	hand-written	**tool-based**	evolutionary algorithm
MathPrompter [Imani et al., 2023]	math	hand-written	**tool-based**	ensemble
Program-of-thoughts [Chen et al., 2022]	math word	hand-written, Codex	**Python+Consist.**	decouple reason/compute
Program-aided-language [Gao et al., 2023]	math word	hand-written, Codex	**NLP/Python**	ensemble
Refiner [Paul et al., 2023]	math word	finetune	**critic model**	gen/crit feedback
Self-corrector [Welleck et al., 2022]	math word	finetune	**corrector model**	gen/corr feedback
Self-improvement [Huang et al., 2022a]	math word	finetune	**self-assessment**	CoT/consistency
Say-can [Ahn et al., 2022]	robot	model-generated	**external model**	greedy
Inner-monologue [Huang et al., 2022b]	robot	hand-written	**various**	greedy
Self-taught-reasoner [Zelikman et al., 2022]	math word	finetune	**augmentation**	greedy/feedback
Least-to-most [Zhou et al., 2022]	math word	hand-written	self-assessment	**curriculum**
Progressive-hint [Zheng et al., 2023]	math word	model-generated	self-assessment	**stable prompt**
Self-refine [Madaan et al., 2023]	math word	model-generated	self-assessment	**greedy/feedback**
Tree-of-thoughts [Yao et al., 2024]	puzzles	model-generated	self-assessment	**BFS/DFS**
Buffer-of-thoughts [Yang et al., 2024]	math word	thought template	self-assessment	**buffer manager**
Beam-search [Xie et al., 2024]	math word	model-generated	self-assessment	**Beam Search**
ReAct [Yao et al., 2022]	action	external knowledge	self-assessment	**reinforcement learning**
Reflexion [Shinn et al., 2024]	decision	model-generated	ext model	**reinforcement learning**
Voyager [Wang et al., 2023]	Minecraft	model-generated	Minecraft	**reinforcement learning**

Source: Plaat, A., Wong, A., Verberne, S., Broekens, J., van Stein, N., & Back, T. (2024). Reasoning with Large Language Models, a Survey. arXiv preprint arXiv:2407.11511.

Self-Refine: Iterative refinement with self-feedback



(a) **Dialogue:** x, $\mathbf{y_t}$

```
User: I am interested
in playing Table
tennis.

Response: I'm sure
it's a great way to
socialize, stay active
```

(b) **FEEDBACK** $\mathbf{fb}$

```
Engaging: Provides no
information about table
tennis or how to play it.

User understanding: Lacks
understanding of user's
needs and state of mind.
```

(c) **REFINE** $\mathbf{y_{t+1}}$

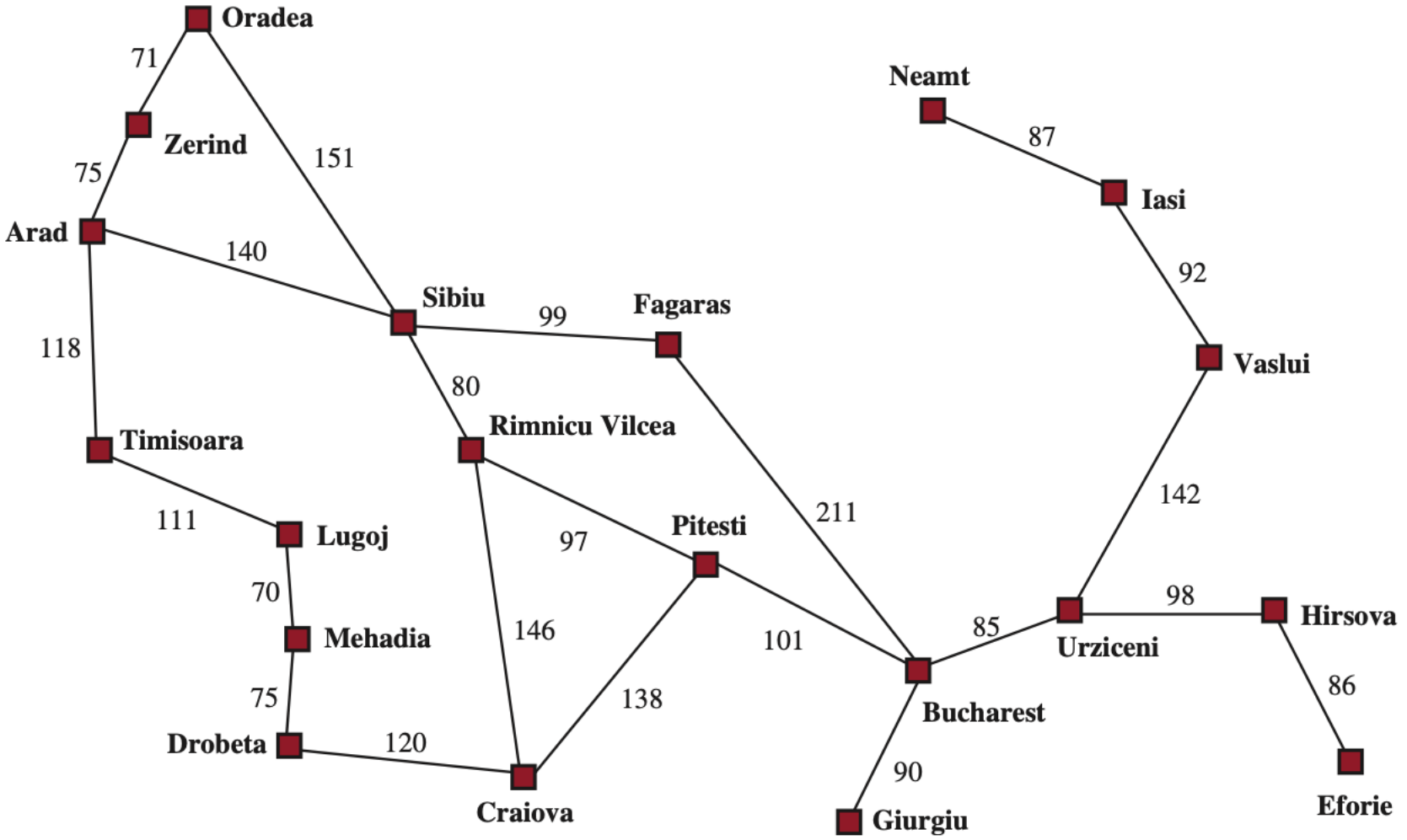
```
Response (refined): That's
great to hear (...) ! It's
a fun sport requiring
quick reflexes and good
hand-eye coordination.
Have you played before, or
are you looking to learn?
```

Source: Madaan, Aman, Niket Tandon, Prakhar Gupta, Skyler Hallinan, Luyu Gao, Sarah Wiegreffe, Uri Alon et al. "Self-refine: Iterative refinement with self-feedback." Advances in Neural Information Processing Systems 36 (2024).

Solving Problems by Searching

AI: Solving Problems by Searching

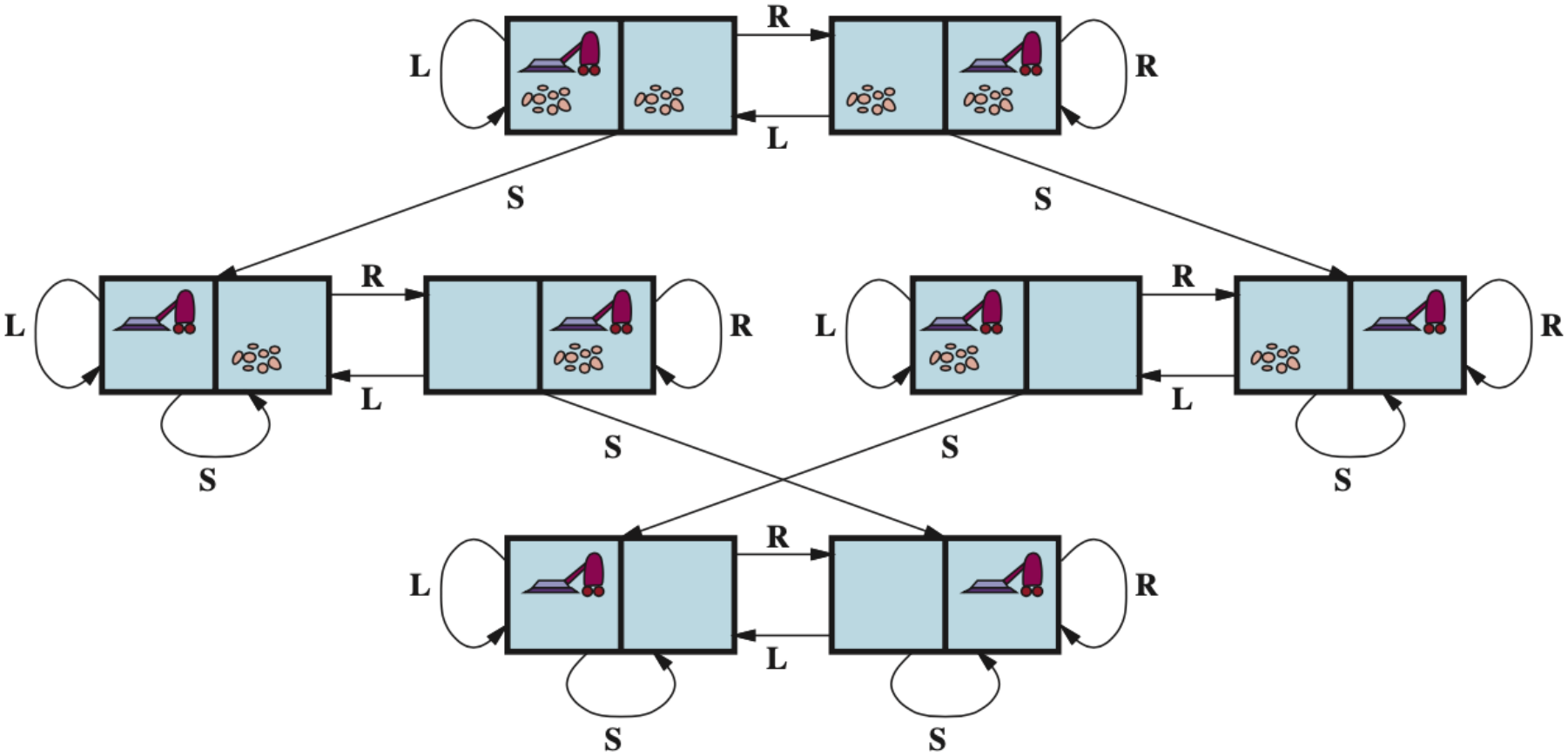
A simplified road map of part of Romania, with road distances in miles.



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

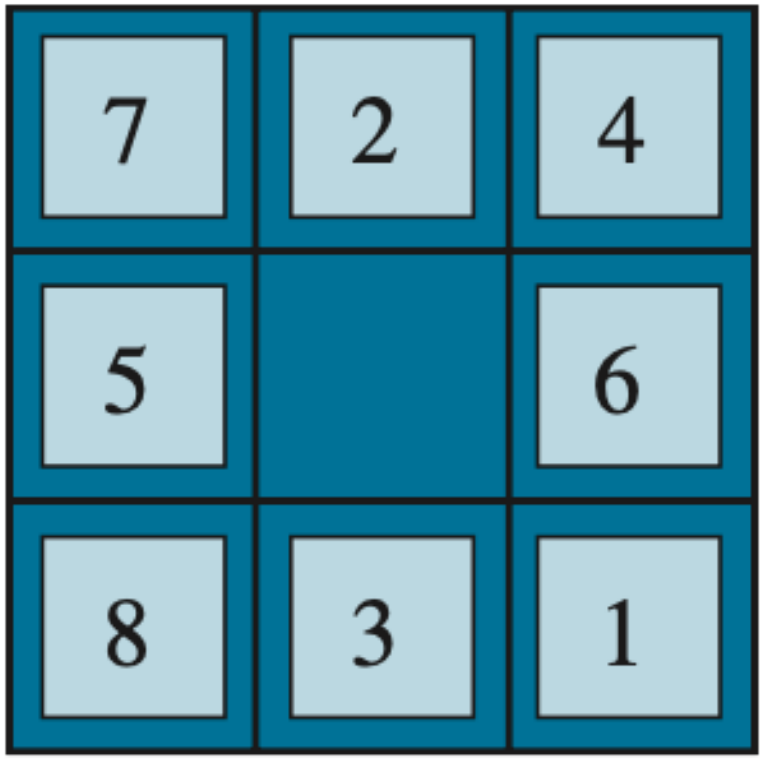
The state-space graph for the two-cell vacuum world

There are 8 states and three actions for each state:
L = *Left*, R = *Right*, S = *Suck*.

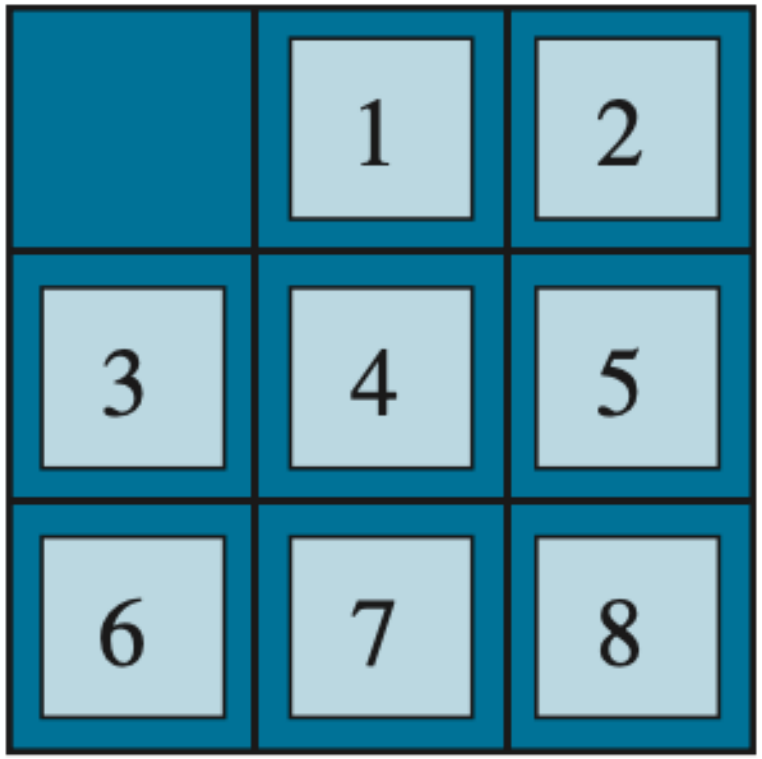


Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A typical instance of the 8-puzzle



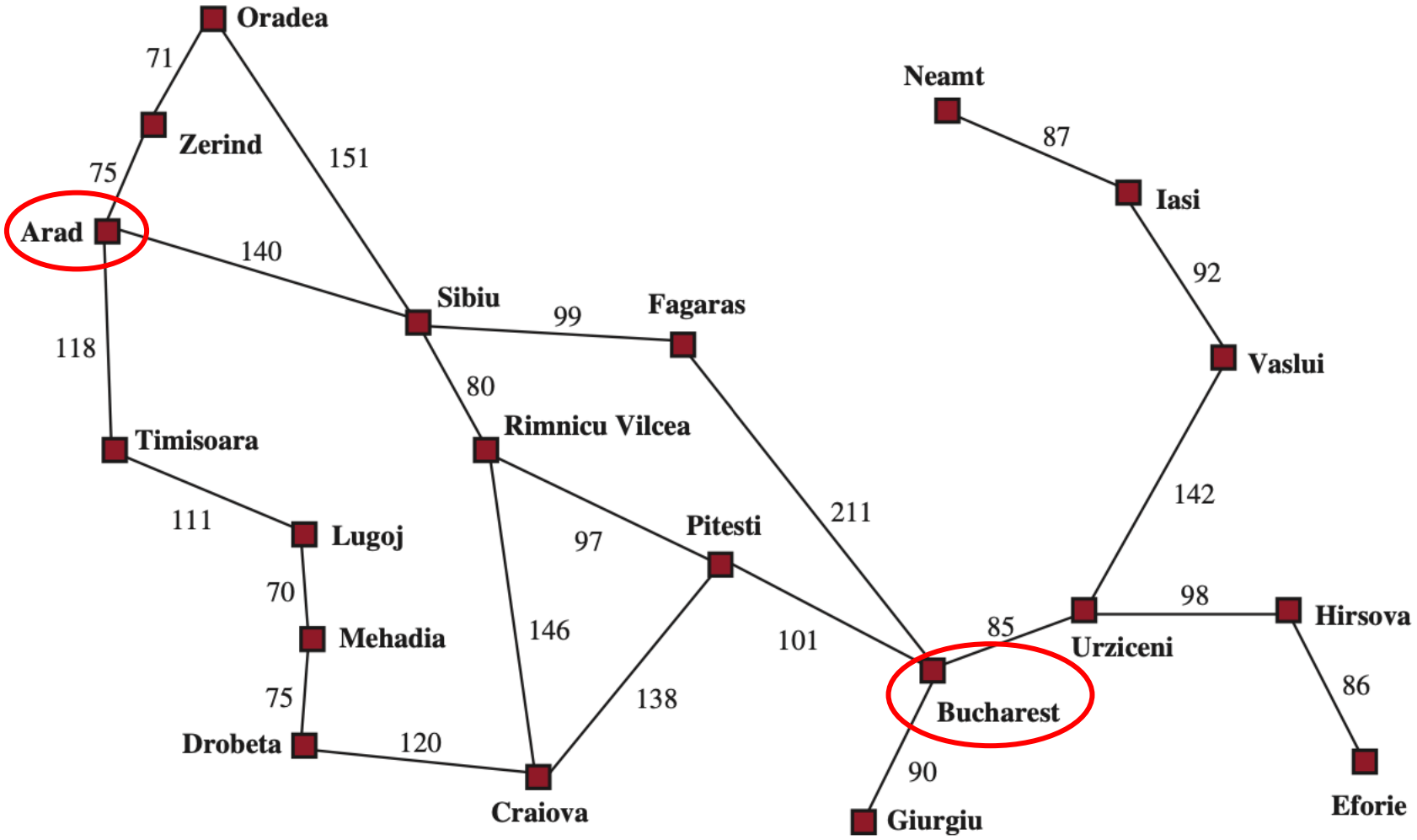
Start State



Goal State

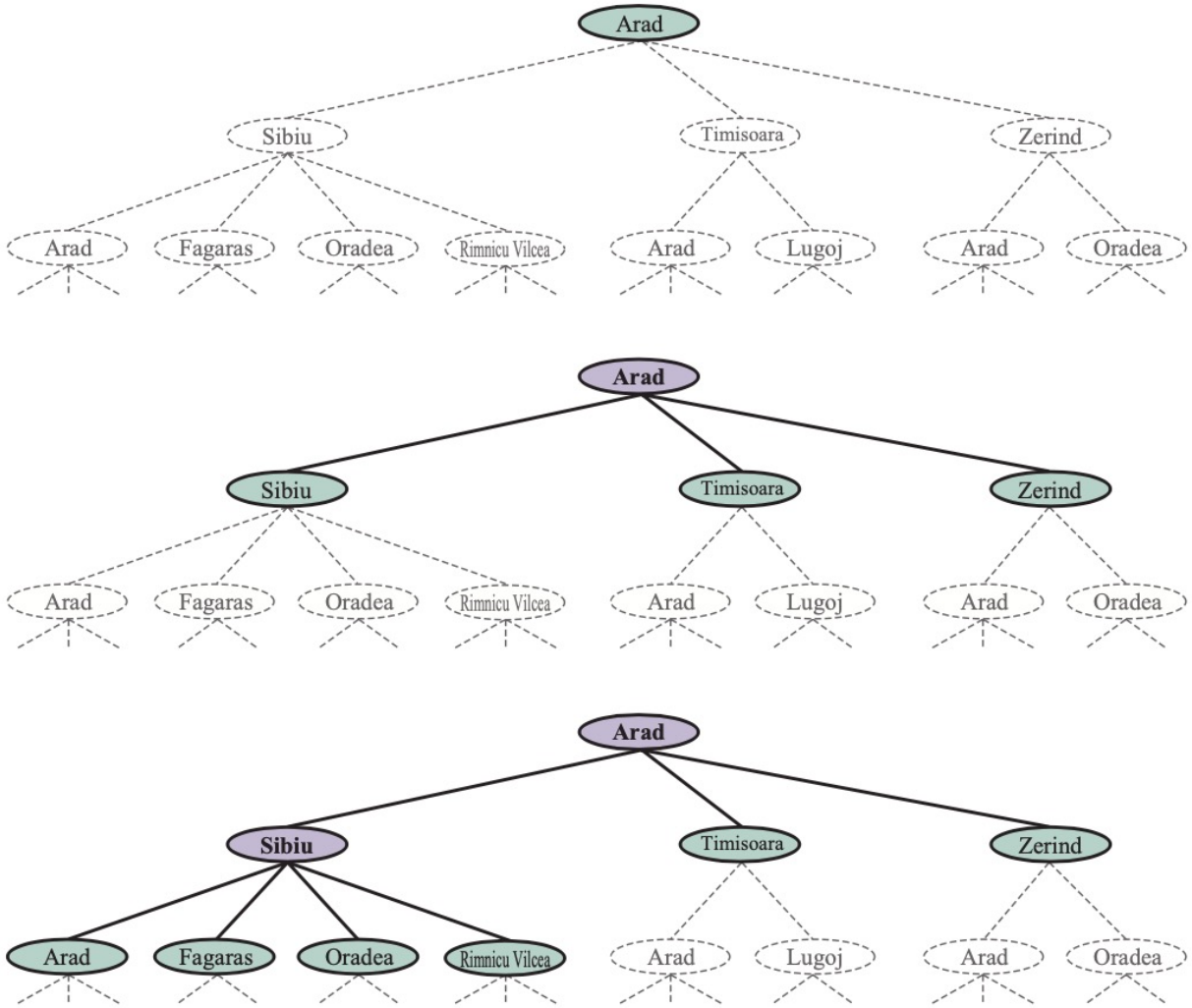
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Arad to Bucharest



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Three partial search trees for finding a route from Arad to Bucharest



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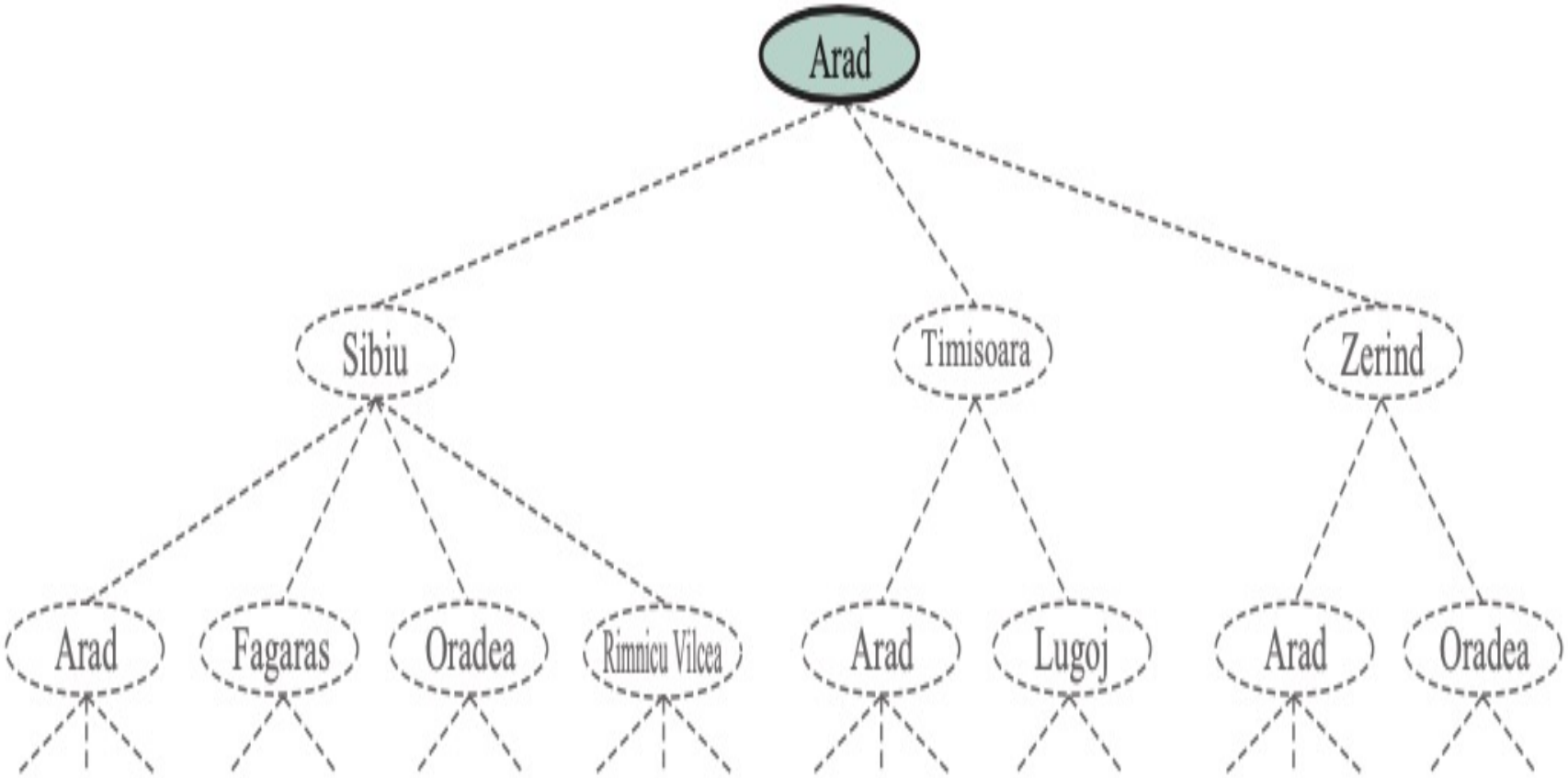

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

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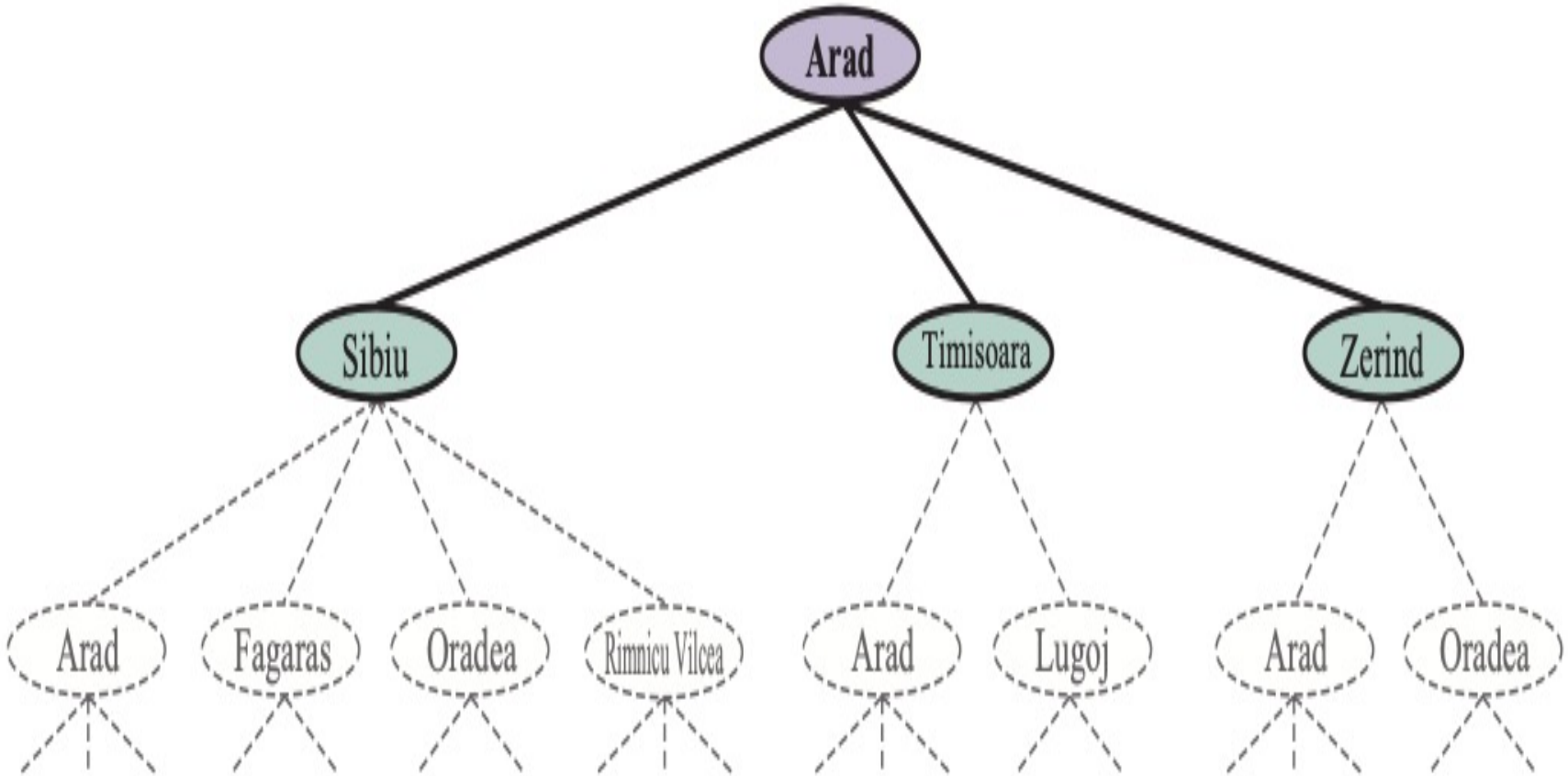

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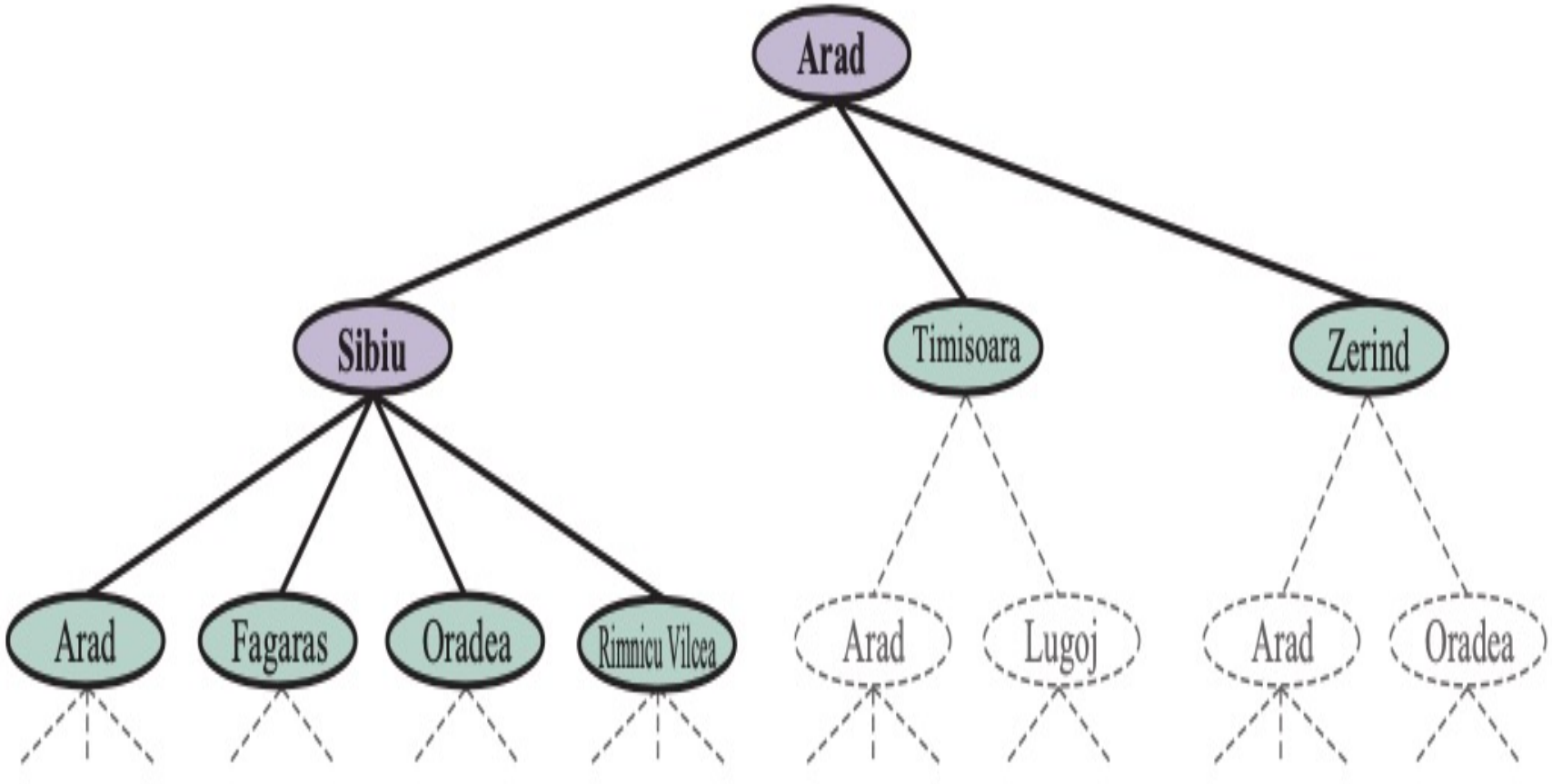
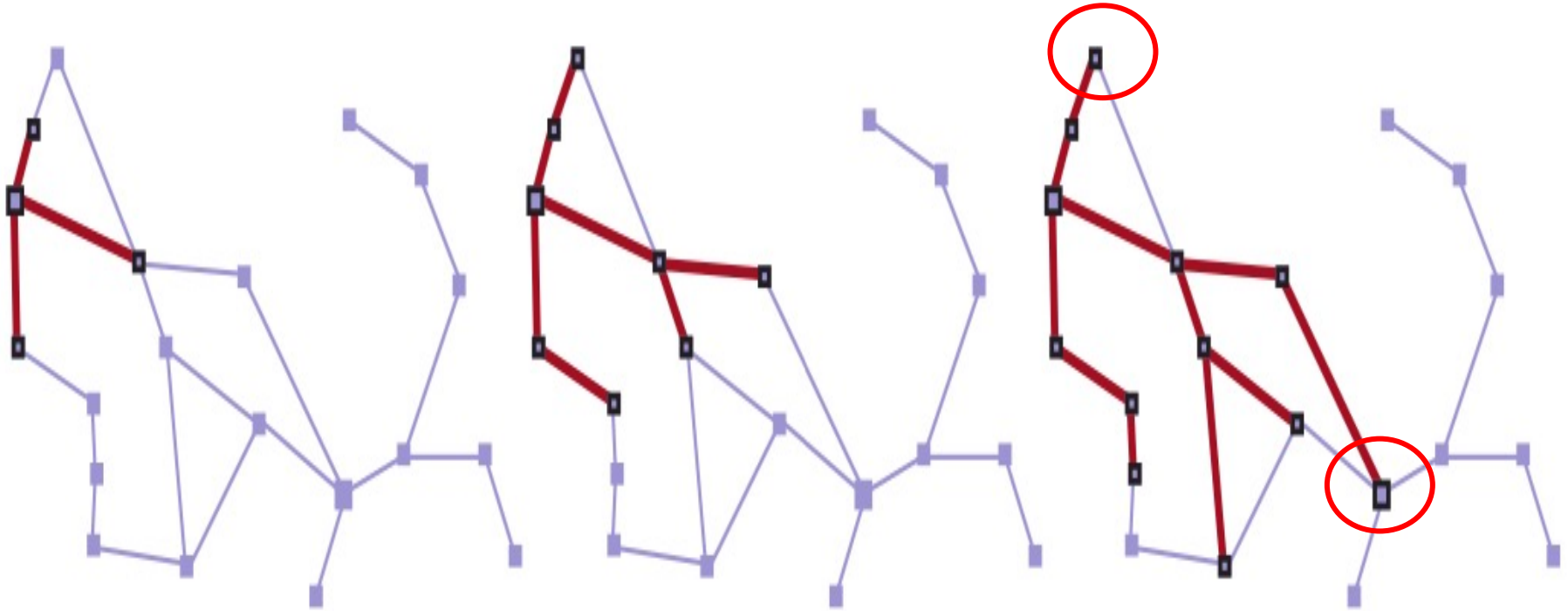
Three partial search trees for finding a route from Arad to Bucharest



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A sequence of search trees generated by a graph search on the Romania problem

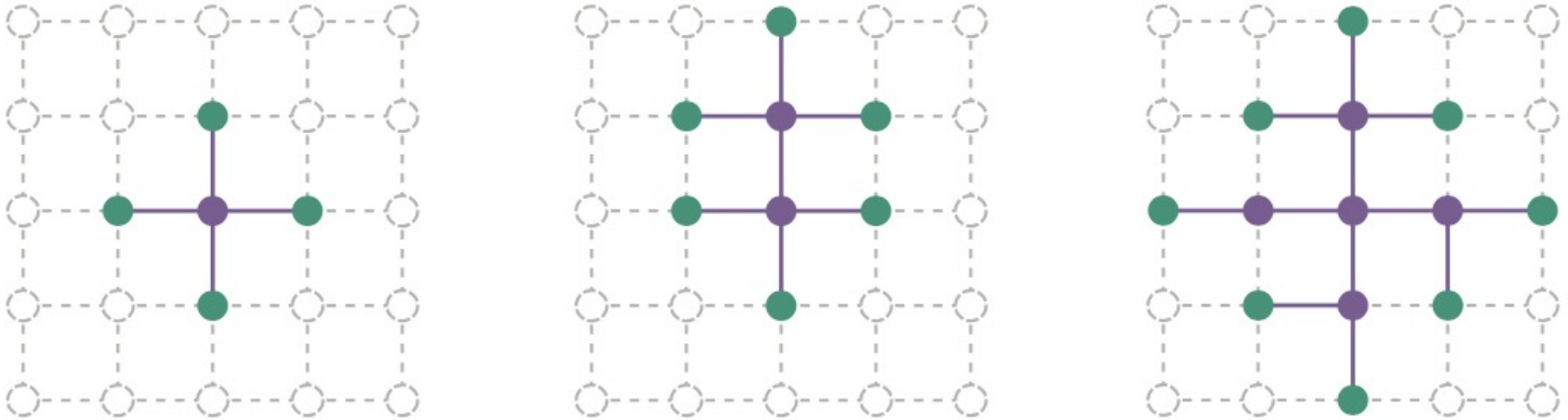


Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

The Separation Property of Graph Search

illustrated on a rectangular-grid problem

The frontier (green) separates
the interior (lavender) from
the exterior (faint dashed)



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

The Best-First Search (BFS) Algorithm

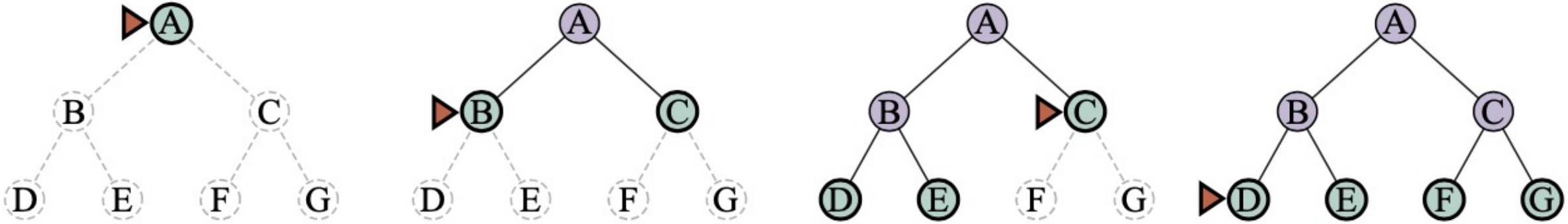
```
function BEST-FIRST-SEARCH(problem, f) returns a solution node or failure
    node ← NODE(STATE=problem.INITIAL)
    frontier ← a priority queue ordered by f, with node as an element
    reached ← a lookup table, with one entry with key problem.INITIAL and value node
    while not IS-EMPTY(frontier) do
        node ← POP(frontier)
        if problem.IS-GOAL(node.STATE) then return node
        for each child in EXPAND(problem, node) do
            s ← child.STATE
            if s is not in reached or child.PATH-COST < reached[s].PATH-COST then
                reached[s] ← child
                add child to frontier
    return failure

function EXPAND(problem, node) yields nodes
    s ← node.STATE
    for each action in problem.ACTIONS(s) do
        s' ← problem.RESULT(s, action)
        cost ← node.PATH-COST + problem.ACTION-COST(s, action, s')
        yield NODE(STATE=s', PARENT=node, ACTION=action, PATH-COST=cost)
```

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Breadth-First Search on a Simple Binary Tree

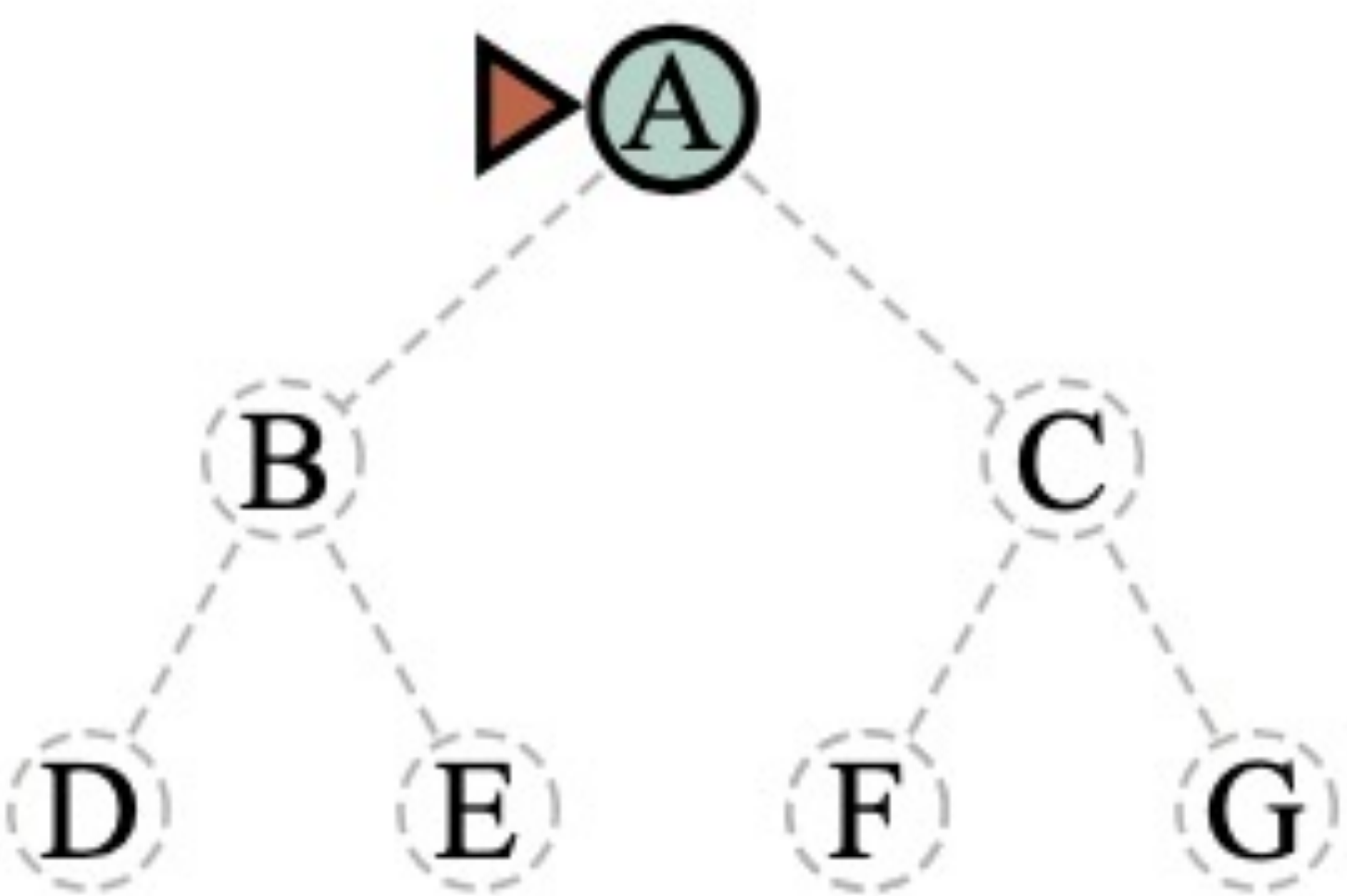
Bread-First Search (BFS)



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Breadth-First Search on a Simple Binary Tree

Bread-First Search (BFS)



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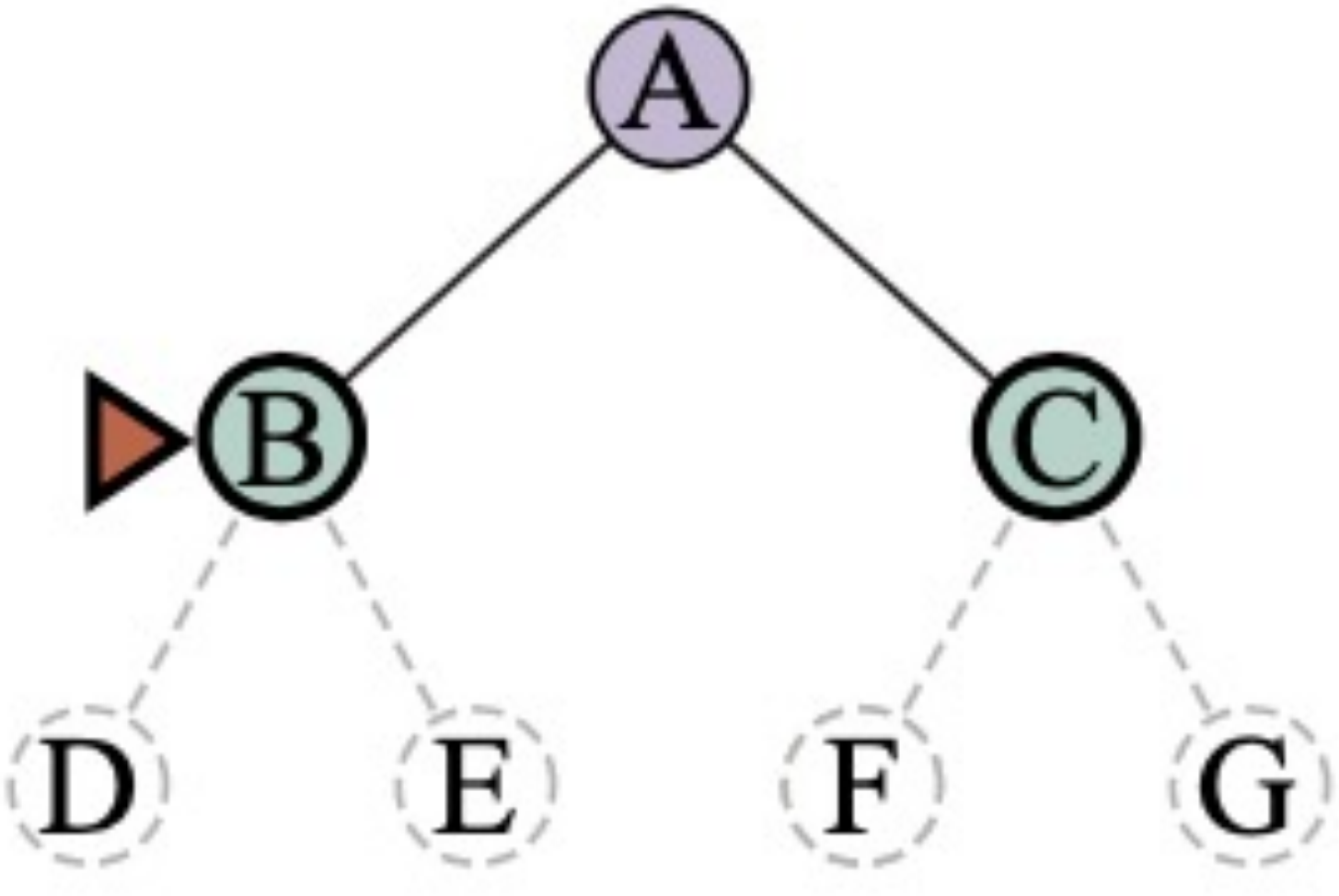
Breadth-First Search on a Simple Binary Tree

Bread-First Search (BFS)



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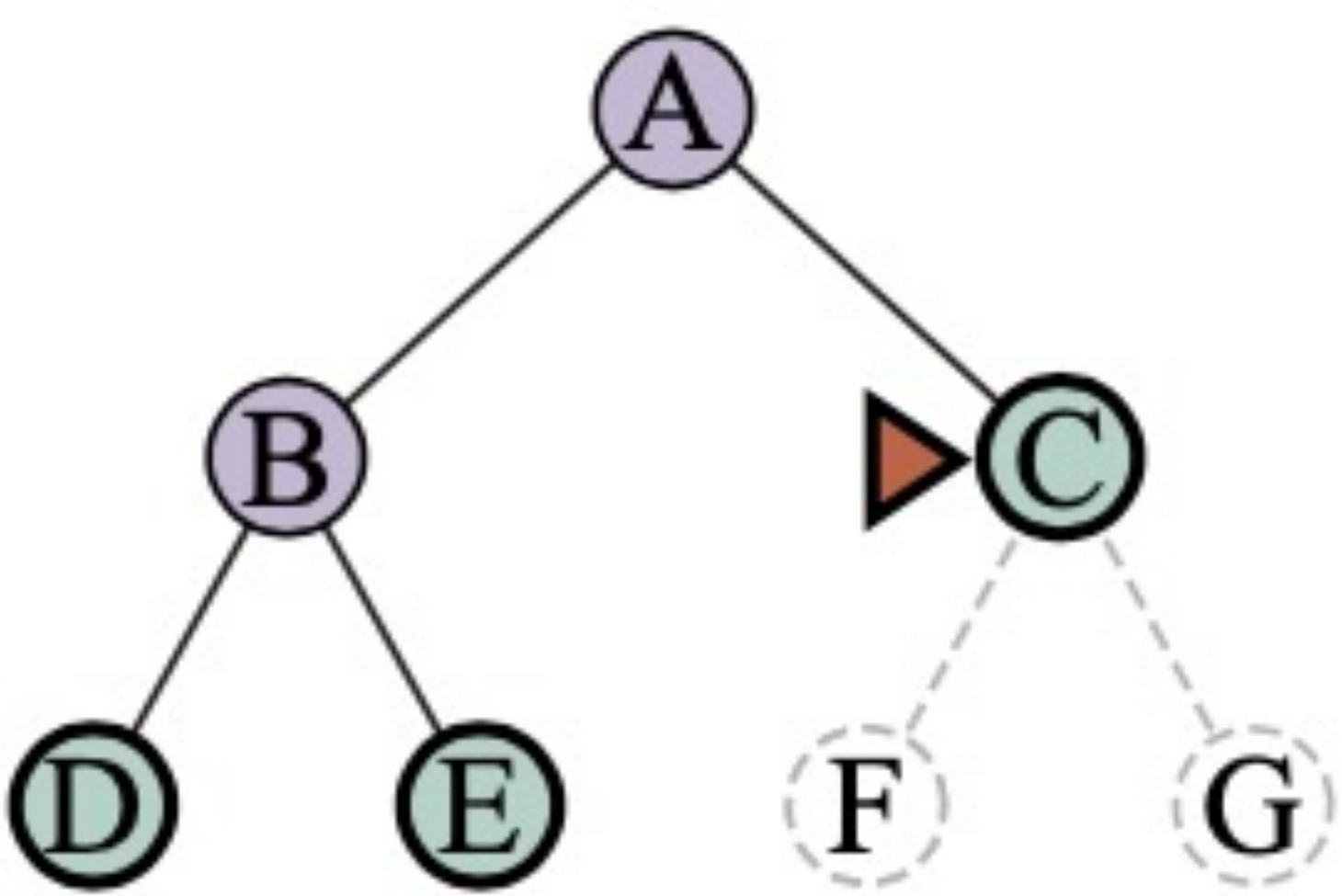
Breadth-First Search on a Simple Binary Tree

Bread-First Search (BFS)



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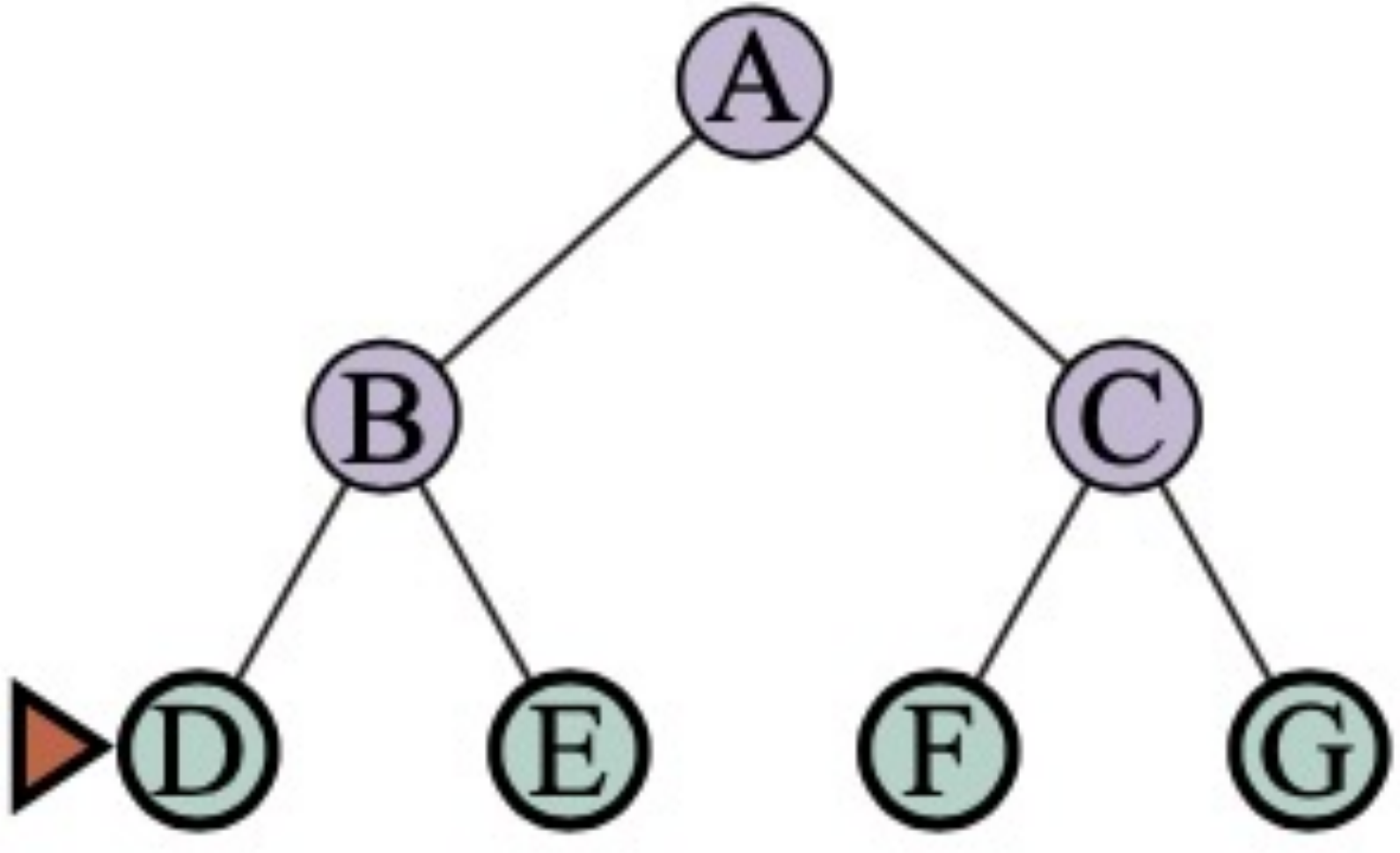
Breadth-First Search on a Simple Binary Tree

Bread-First Search (BFS)



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

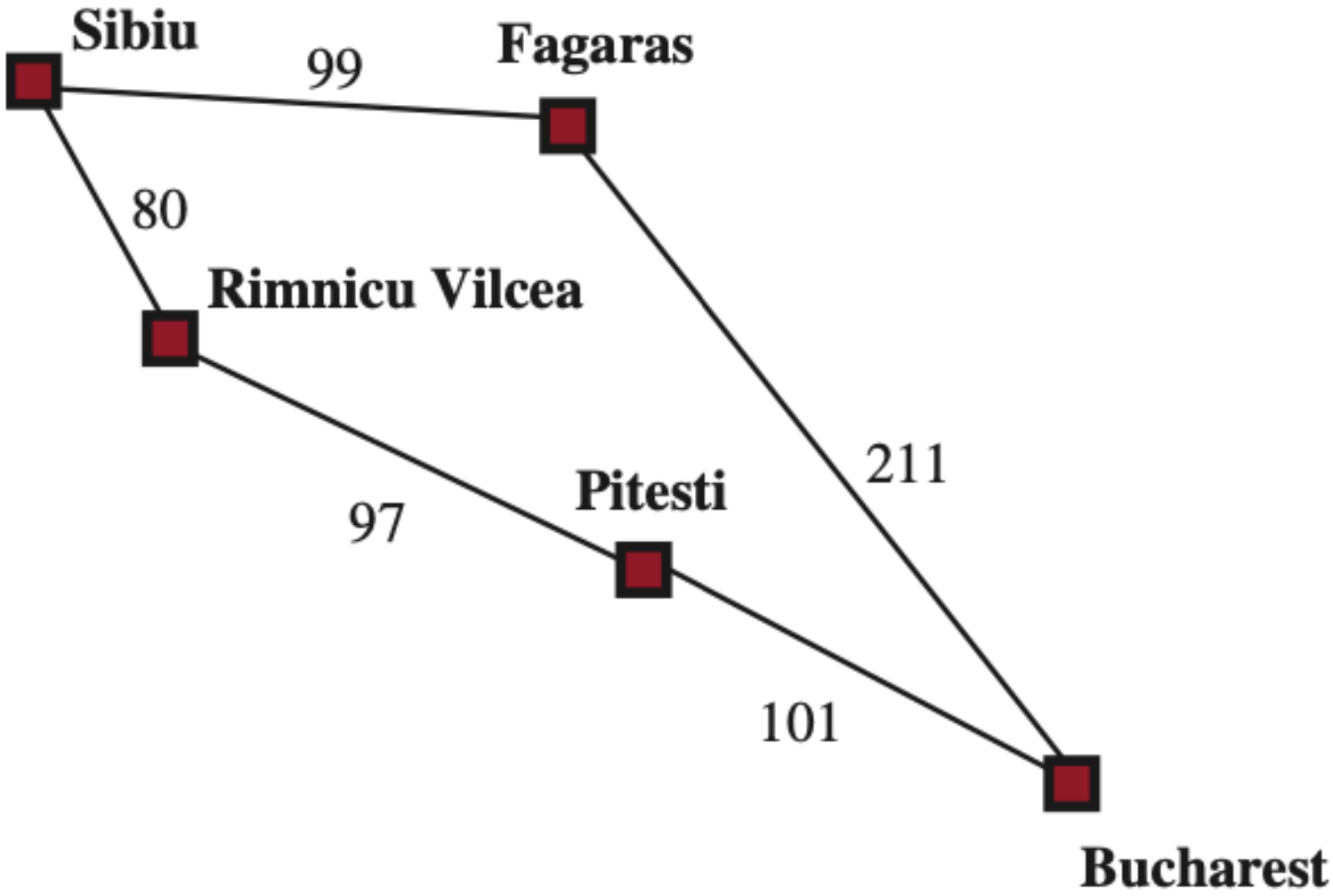
Breadth-First Search and Uniform-Cost Search Algorithms

```
function BREADTH-FIRST-SEARCH(problem) returns a solution node or failure
  node ← NODE(problem.INITIAL)
  if problem.IS-GOAL(node.STATE) then return node
  frontier ← a FIFO queue, with node as an element
  reached ← {problem.INITIAL}
  while not IS-EMPTY(frontier) do
    node ← POP(frontier)
    for each child in EXPAND(problem, node) do
      s ← child.STATE
      if problem.IS-GOAL(s) then return child
      if s is not in reached then
        add s to reached
        add child to frontier
  return failure

function UNIFORM-COST-SEARCH(problem) returns a solution node, or failure
  return BEST-FIRST-SEARCH(problem, PATH-COST)
```

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

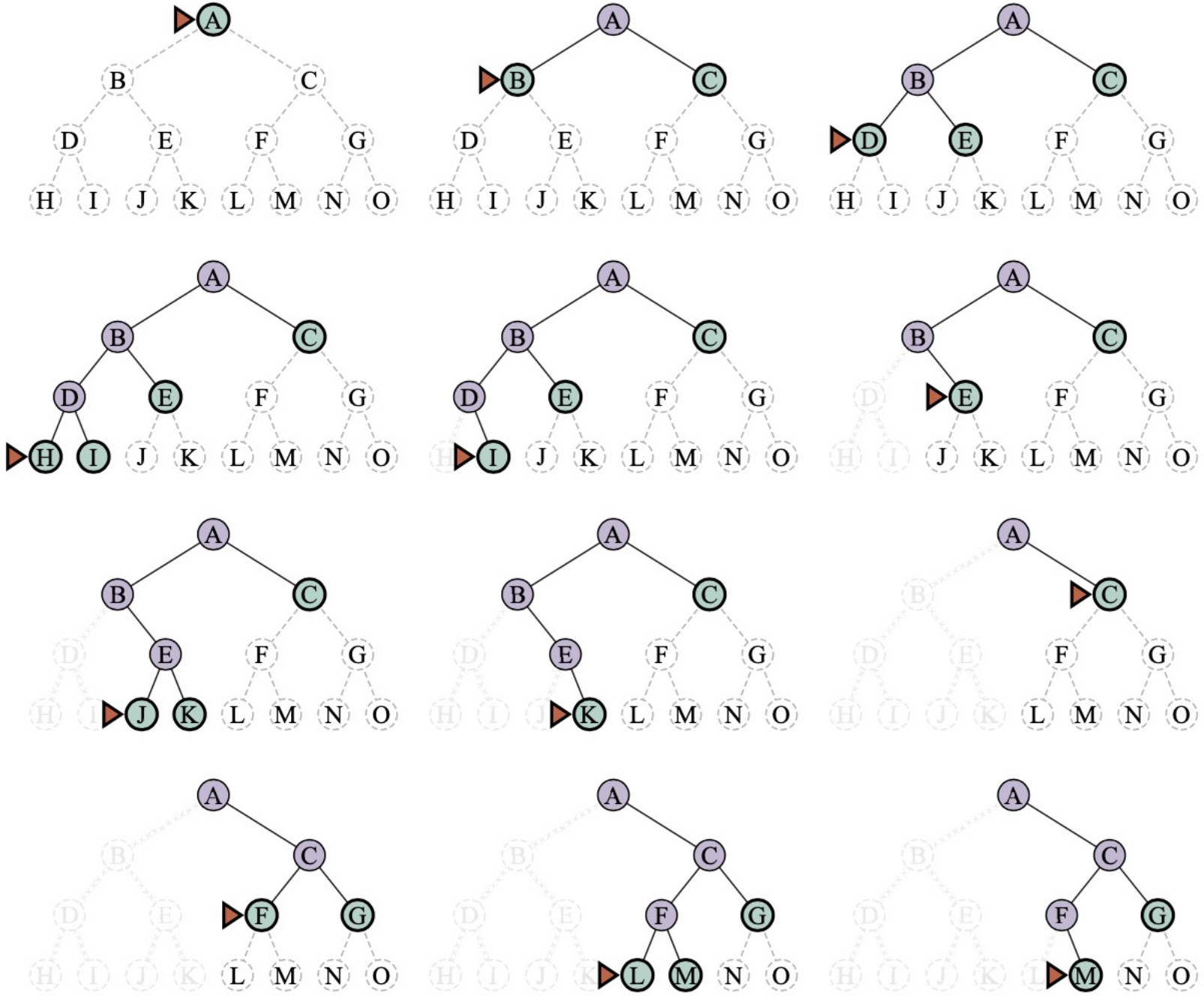
Part of the Romania State Space
Uniform-Cost Search



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Depth-First Search (DFS)

Depth-First Search (DFS)



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

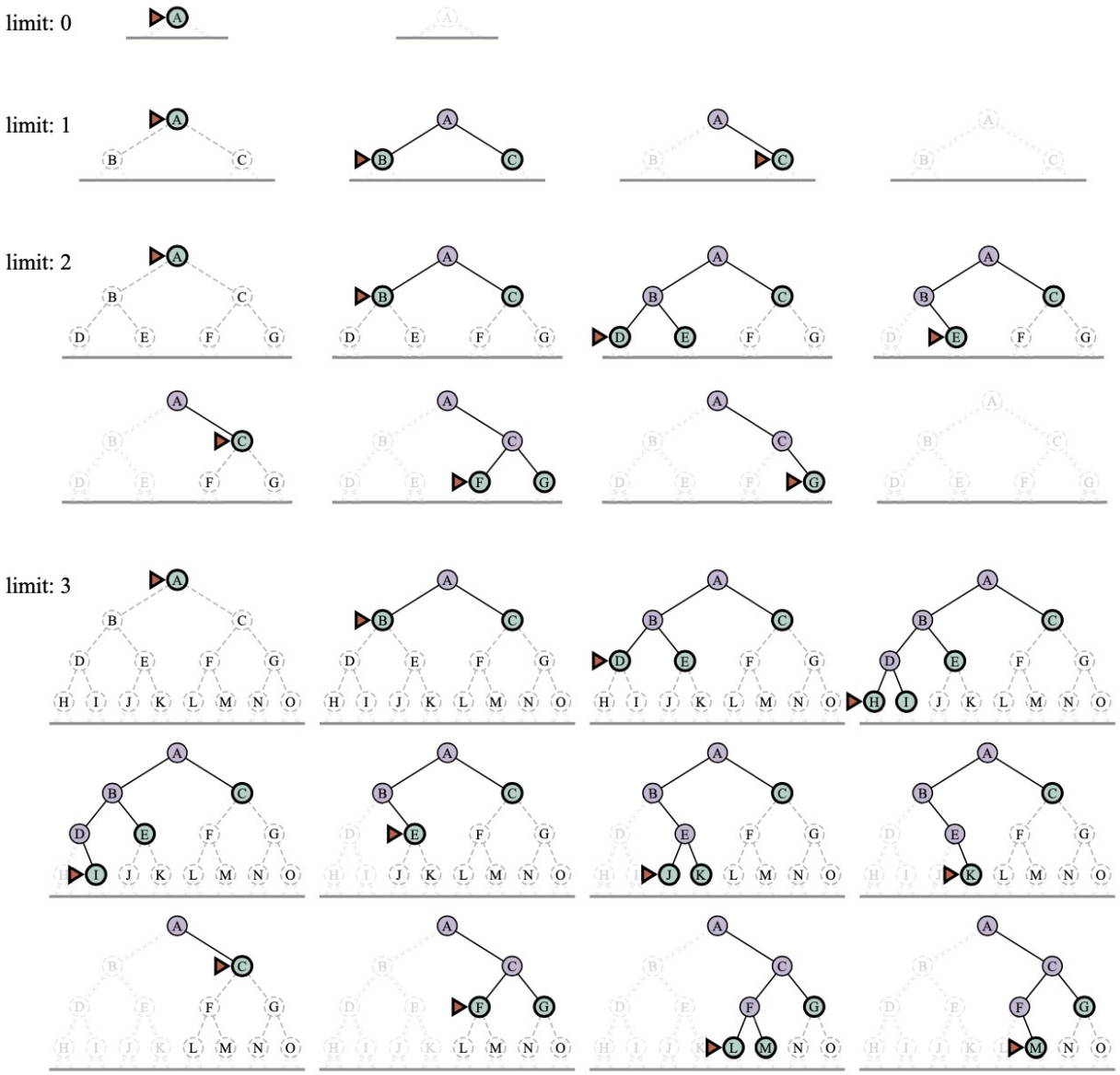
Iterative deepening and depth-limited tree-like search

```
function ITERATIVE-DEEPENING-SEARCH(problem) returns a solution node or failure
  for depth = 0 to ∞ do
    result ← DEPTH-LIMITED-SEARCH(problem, depth)
    if result ≠ cutoff then return result

function DEPTH-LIMITED-SEARCH(problem, ℓ) returns a node or failure or cutoff
  frontier ← a LIFO queue (stack) with NODE(problem.INITIAL) as an element
  result ← failure
  while not IS-EMPTY(frontier) do
    node ← POP(frontier)
    if problem.IS-GOAL(node.STATE) then return node
    if DEPTH(node) > ℓ then
      result ← cutoff
    else if not IS-CYCLE(node) do
      for each child in EXPAND(problem, node) do
        add child to frontier
  return result
```

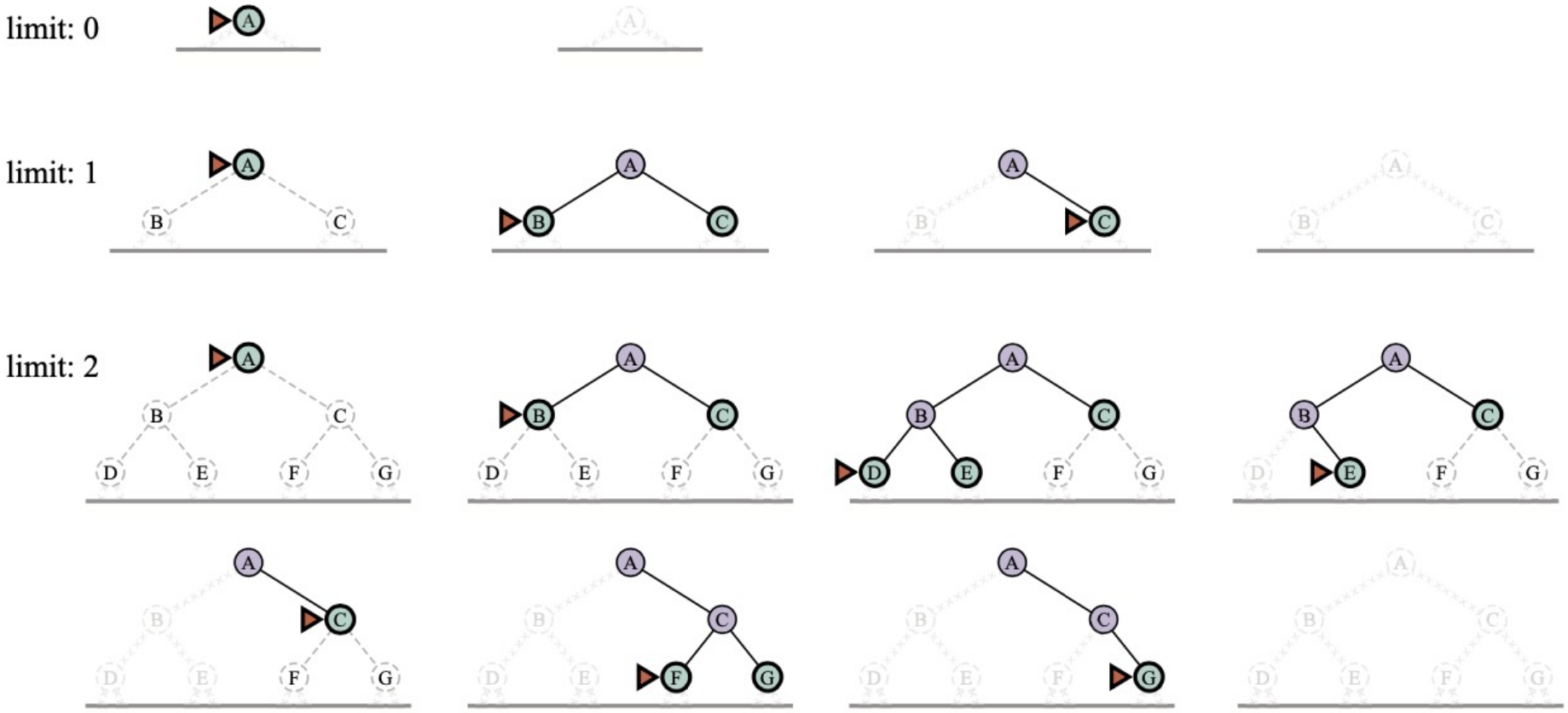
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Four iterations of iterative deepening search



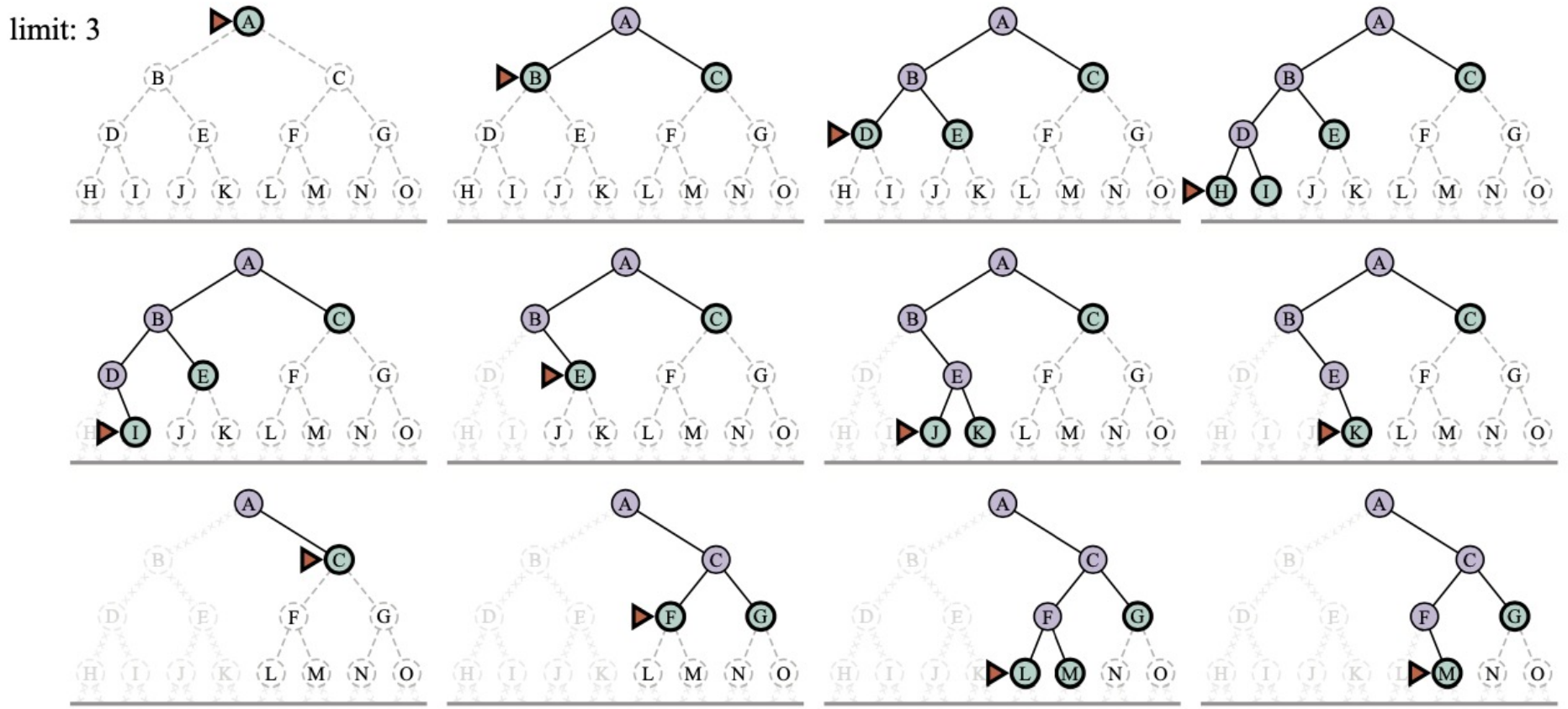
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Four iterations of iterative deepening search



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Four iterations of iterative deepening search



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Bidirectional Best-First Search

keeps two frontiers and two tables of reached states

```
function BIBF-SEARCH(problem_F, f_F, problem_B, f_B) returns a solution node, or failure
  node_F ← NODE(problem_F.INITIAL)                    // Node for a start state
  node_B ← NODE(problem_B.INITIAL)                    // Node for a goal state
  frontier_F ← a priority queue ordered by f_F, with node_F as an element
  frontier_B ← a priority queue ordered by f_B, with node_B as an element
  reached_F ← a lookup table, with one key node_F.STATE and value node_F
  reached_B ← a lookup table, with one key node_B.STATE and value node_B
  solution ← failure
  while not TERMINATED(solution, frontier_F, frontier_B) do
    if f_F(TOP(frontier_F)) < f_B(TOP(frontier_B)) then
      solution ← PROCEED(F, problem_F frontier_F, reached_F, reached_B, solution)
    else solution ← PROCEED(B, problem_B, frontier_B, reached_B, reached_F, solution)
  return solution
```

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Bidirectional Best-First Search

keeps two frontiers and two tables of reached states

```
function PROCEED(dir, problem, frontier, reached, reached2, solution) returns a solution
        // Expand node on frontier; check against the other frontier in reached2.
        // The variable "dir" is the direction: either F for forward or B for backward.
  node ← POP(frontier)
  for each child in EXPAND(problem, node) do
    s ← child.STATE
    if s not in reached or PATH-COST(child) < PATH-COST(reached[s]) then
      reached[s] ← child
      add child to frontier
      if s is in reached2 then
        solution2 ← JOIN-NODES(dir, child, reached2[s]))
        if PATH-COST(solution2) < PATH-COST(solution) then
          solution ← solution2
  return solution
```

Evaluation of search algorithms

Criterion	Breadth-First	Uniform-Cost	Depth-First	Depth-Limited	Iterative Deepening	Bidirectional (if applicable)
Complete?	Yes[1]	Yes[1,2]	No	No	Yes[1]	Yes[1,4]
Optimal cost?	Yes[3]	Yes	No	No	Yes[3]	Yes[3,4]
Time	$O(b^d)$	$O(b^{1+\lfloor C^*/\epsilon \rfloor})$	$O(b^m)$	$O(b^\ell)$	$O(b^d)$	$O(b^{d/2})$
Space	$O(b^d)$	$O(b^{1+\lfloor C^*/\epsilon \rfloor})$	$O(bm)$	$O(b\ell)$	$O(bd)$	$O(b^{d/2})$

b is the branching factor; m is the maximum depth of the search tree;
d is the depth of the shallowest solution, or is m when there is no solution;
ℓ is the depth limit

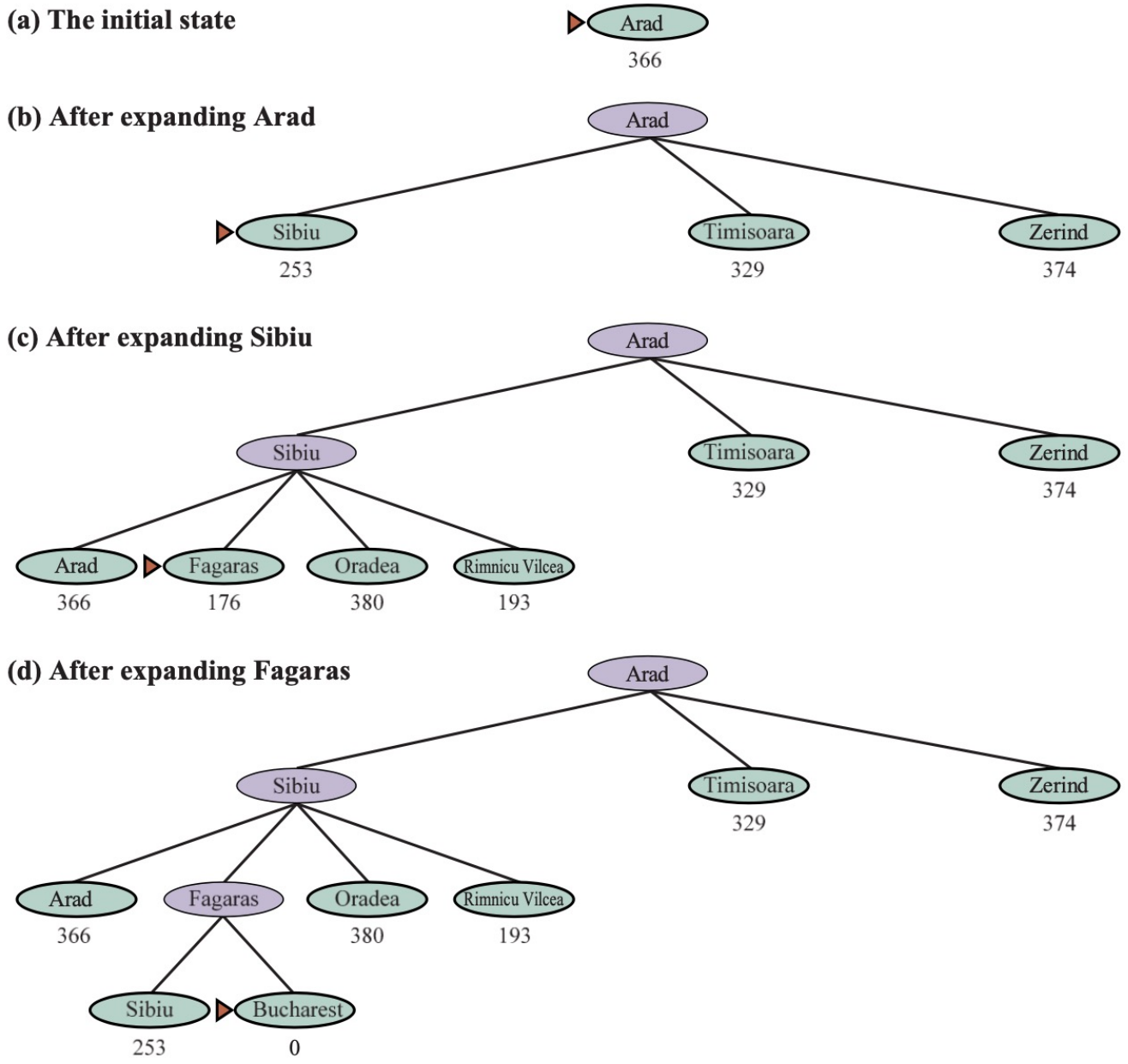
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Values of *hSLD*
—straight-line distances to Bucharest.

Arad	366	**Mehadia**	241
Bucharest	0	**Neamt**	234
Craiova	160	**Oradea**	380
Drobeta	242	**Pitesti**	100
Eforie	161	**Rimnicu Vilcea**	193
Fagaras	176	**Sibiu**	253
Giurgiu	77	**Timisoara**	329
Hirsova	151	**Urziceni**	80
Iasi	226	**Vaslui**	199
Lugoj	244	**Zerind**	374

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

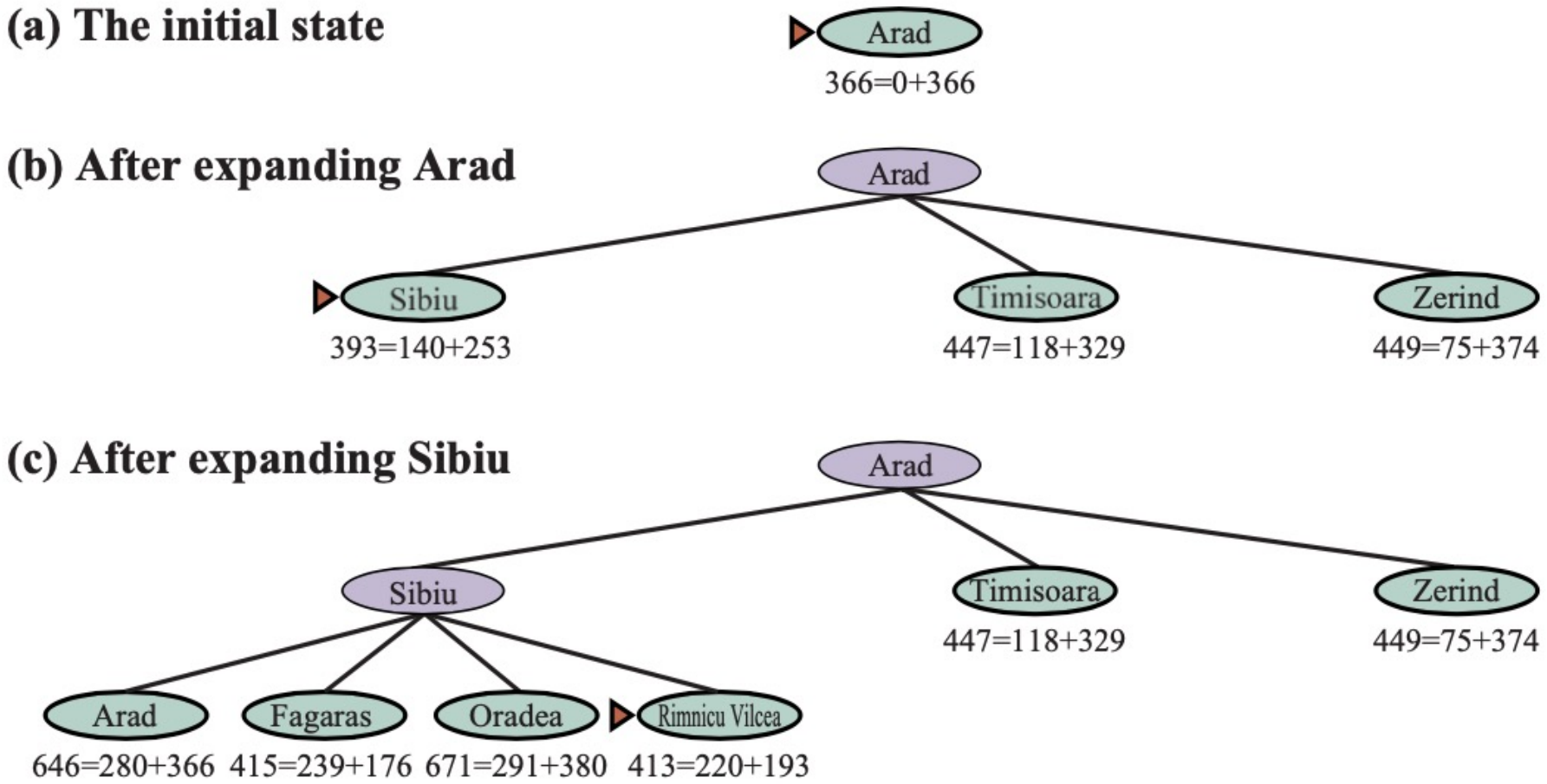
A* search



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A* search

Nodes are labeled with $f = g + h$.
The h values are the Straight-Line Distances heuristic h_{SLD}



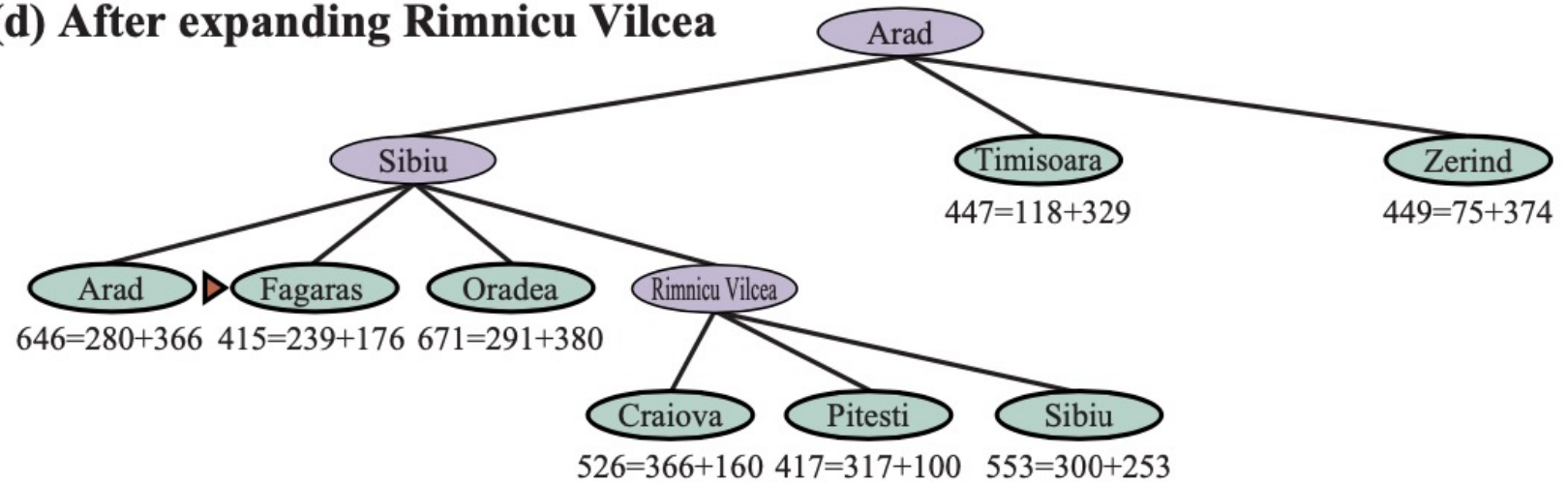
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A* search

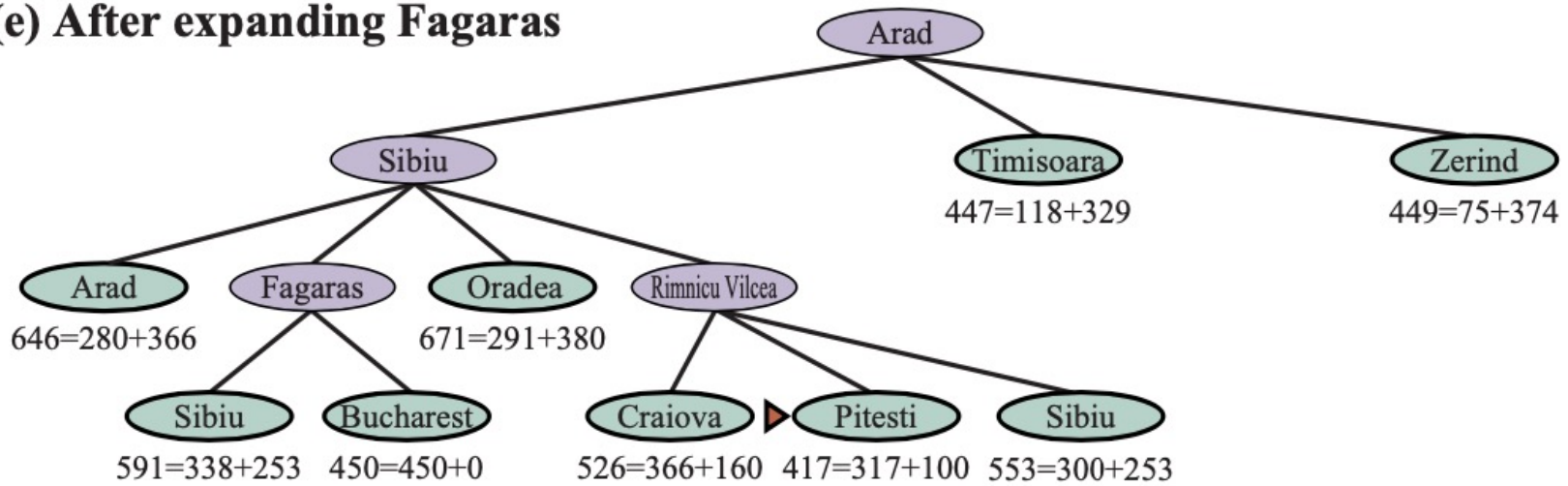
Nodes are labeled with $f = g + h$.

The h values are the Straight-Line Distances heuristic h_{SLD}

(d) After expanding Rimnicu Vilcea



(e) After expanding Fagaras



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A* search

Nodes are labeled with $f = g + h$.
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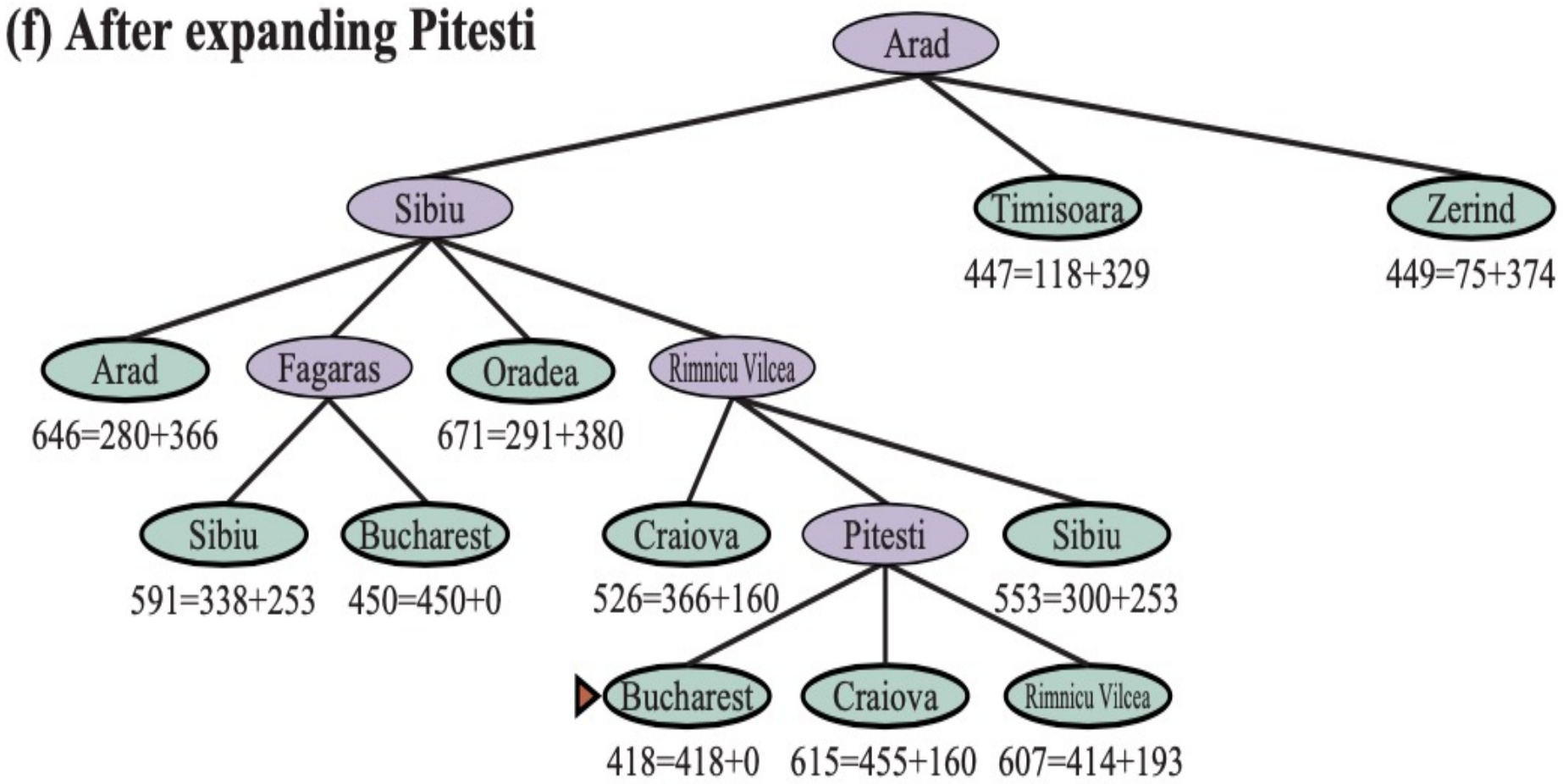
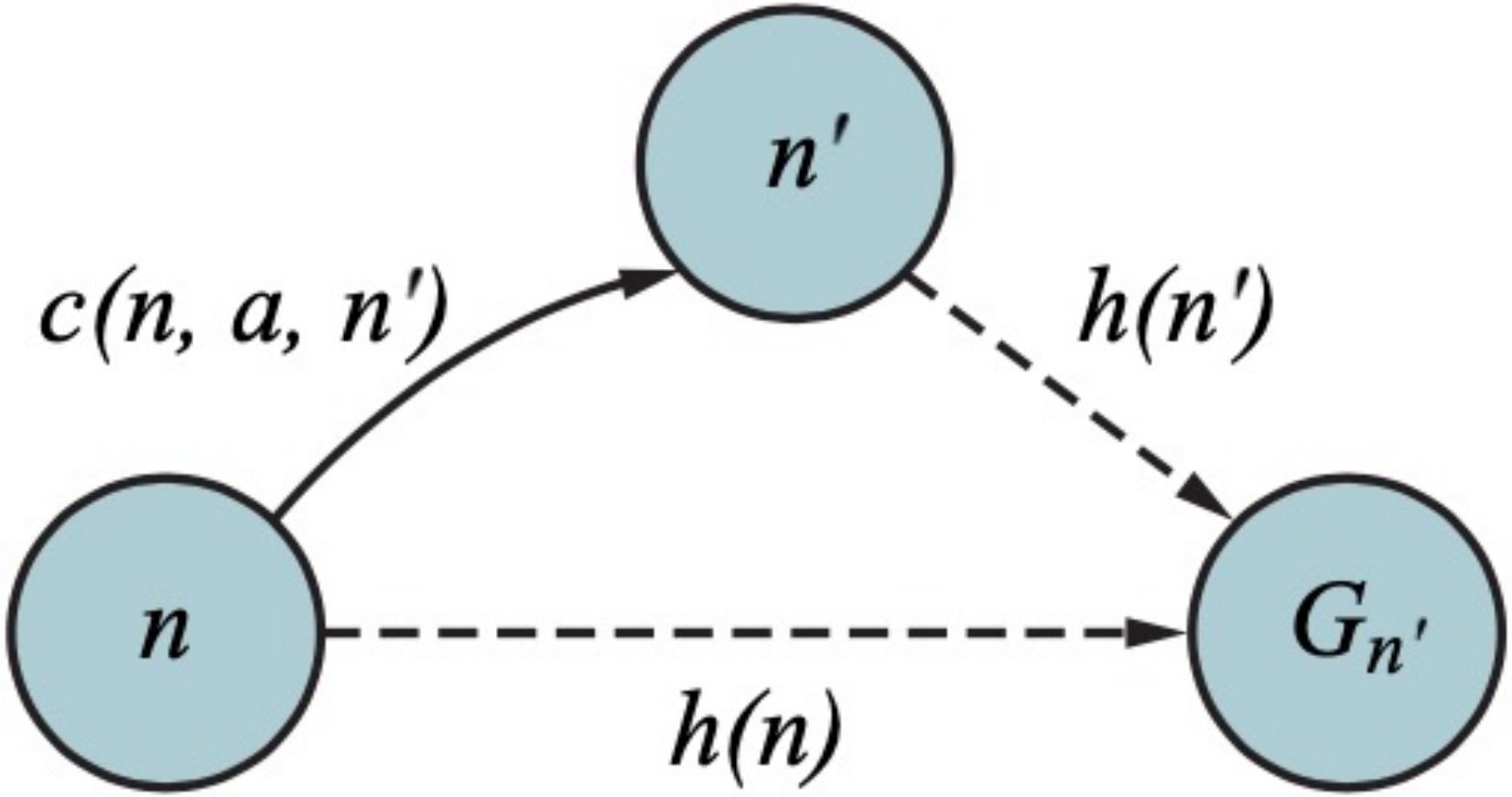


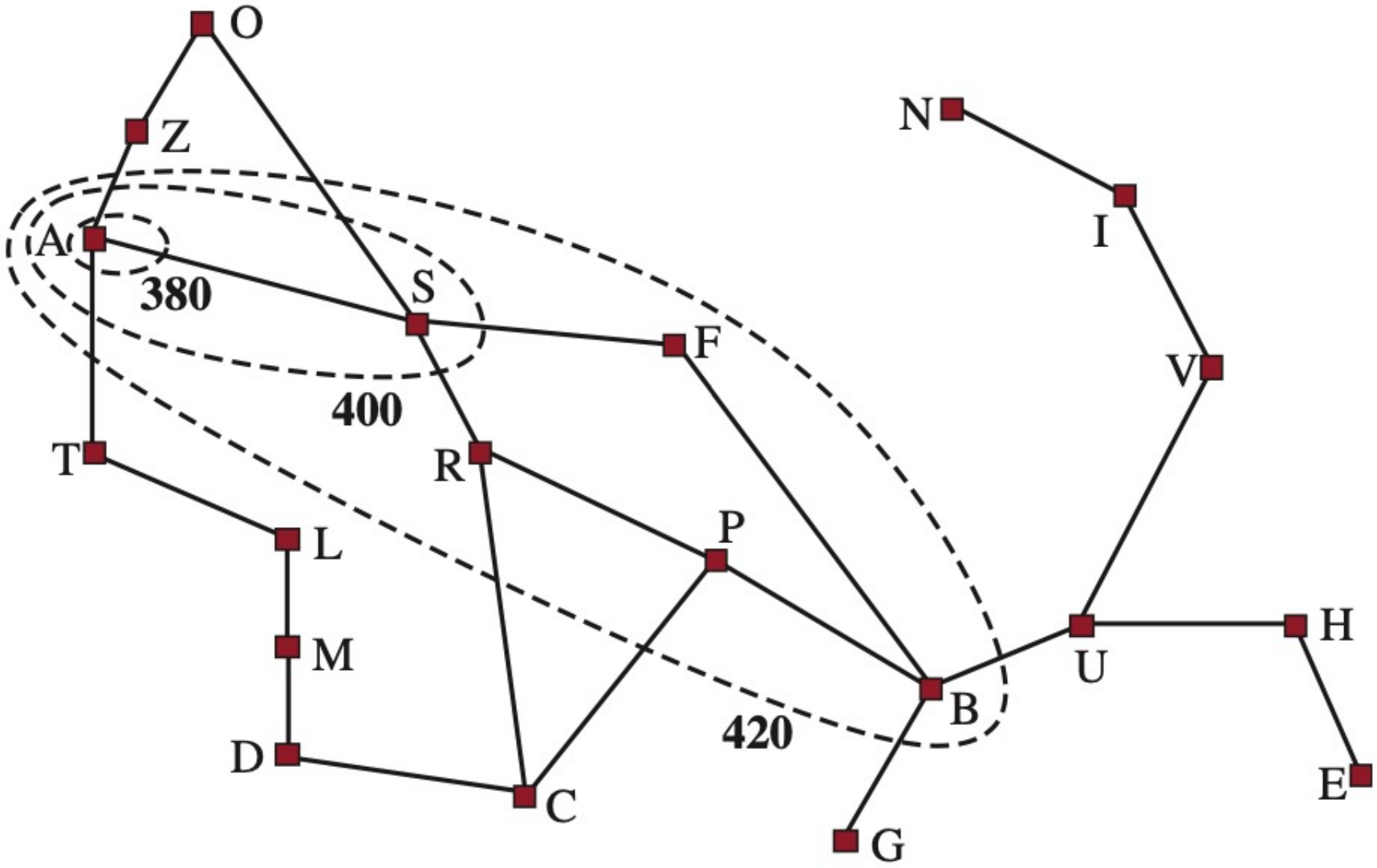
Triangle Inequality



If the heuristic h is consistent, then the single number $h(n)$ will be less than the sum of the cost c(n, a, a′) of the action from n to n′ plus the heuristic estimate h(n′).

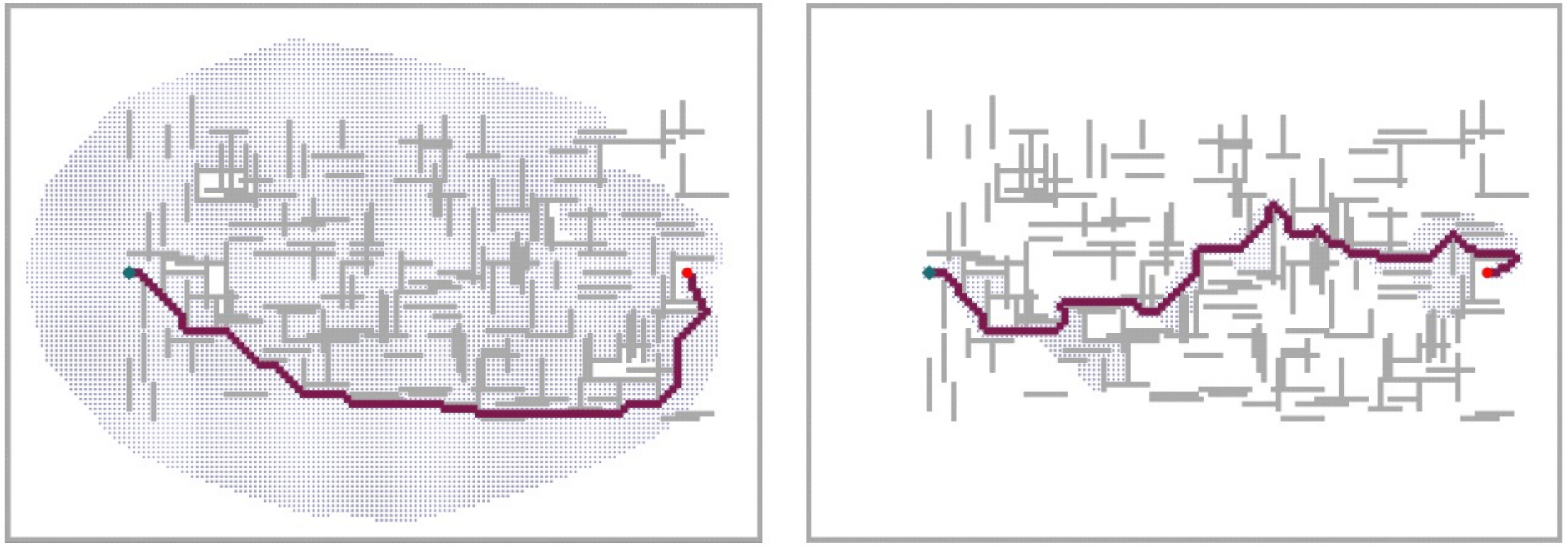
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Map of Romania showing contours *at* *f = 380, f = 400*, and *f = 420*, with Arad as the start state



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

(a) A* Search
(b) Weighted A* Search



(a) (b)

The gray bars are obstacles, the purple line is the path from the green start to red goal, and the small dots are states that were reached by each search.
On this particular problem, weighted A* explores 7 times fewer states and finds a path that is 5% more costly.

Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

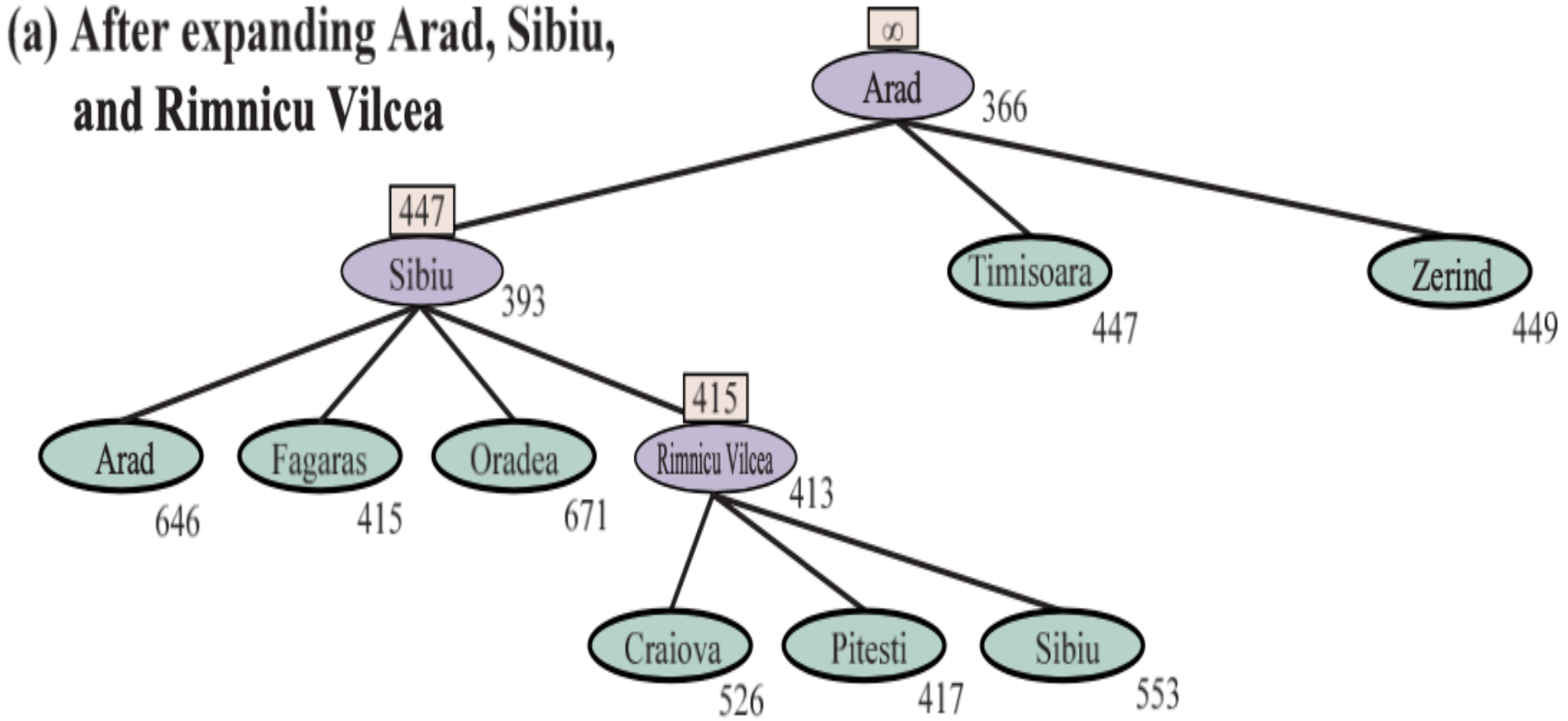
Recursive Best-First Search (RBFS) Algorithm

```
function RECURSIVE-BEST-FIRST-SEARCH(problem) returns a solution or failure
    solution, fvalue ← RBFS(problem, NODE(problem.INITIAL), ∞)
  return solution

function RBFS(problem, node, f_limit) returns a solution or failure, and a new f-cost limit
  if problem.IS-GOAL(node.STATE) then return node
  successors ← LIST(EXPAND(node))
  if successors is empty then return failure, ∞
  for each s in successors do        // update f with value from previous search
      s.f ← max(s.PATH-COST + h(s), node.f))
  while true do
      best ← the node in successors with lowest f-value
      if best.f > f_limit then return failure, best.f
      alternative ← the second-lowest f-value among successors
      result, best.f ← RBFS(problem, best, min(f_limit, alternative))
      if result ≠ failure then return result, best.f
```

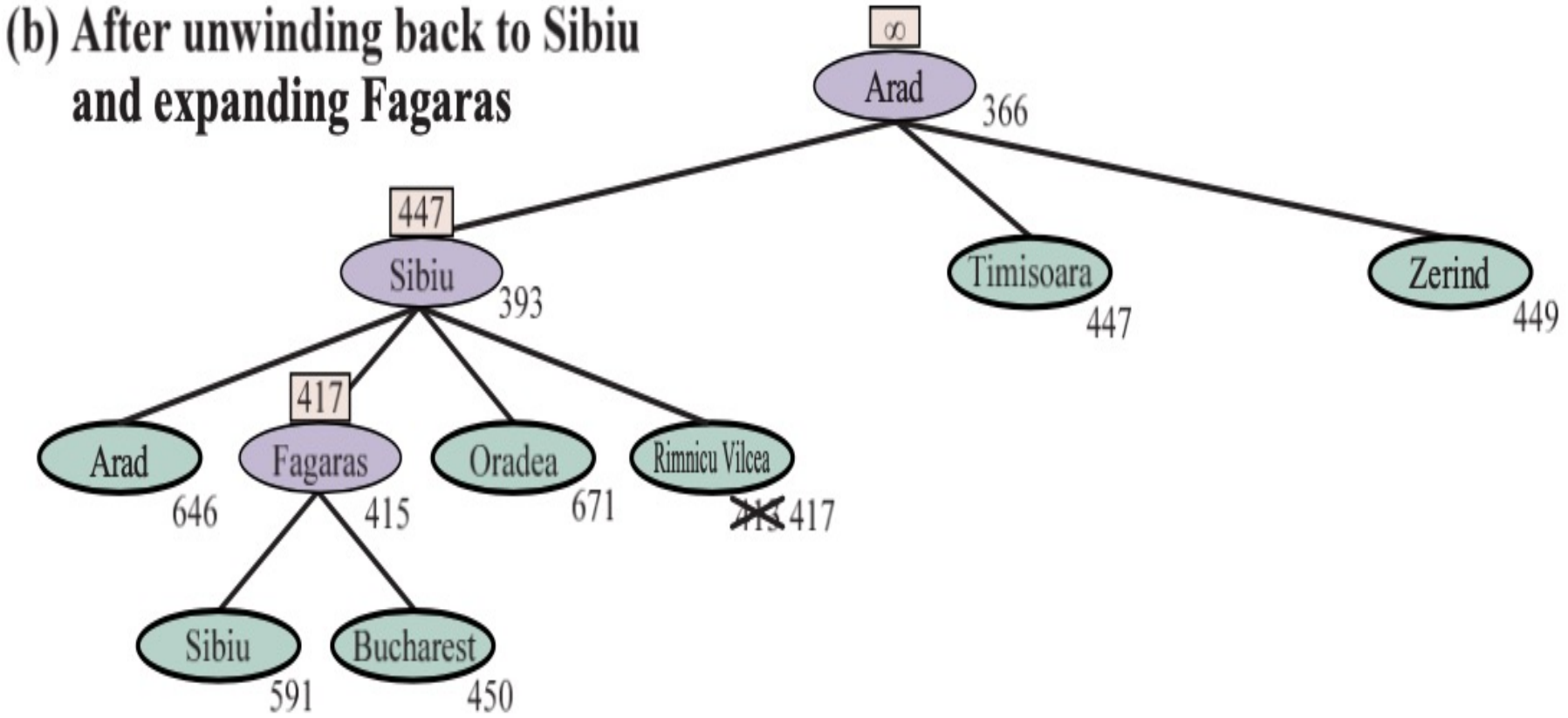
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Recursive Best-First Search (RBFS)



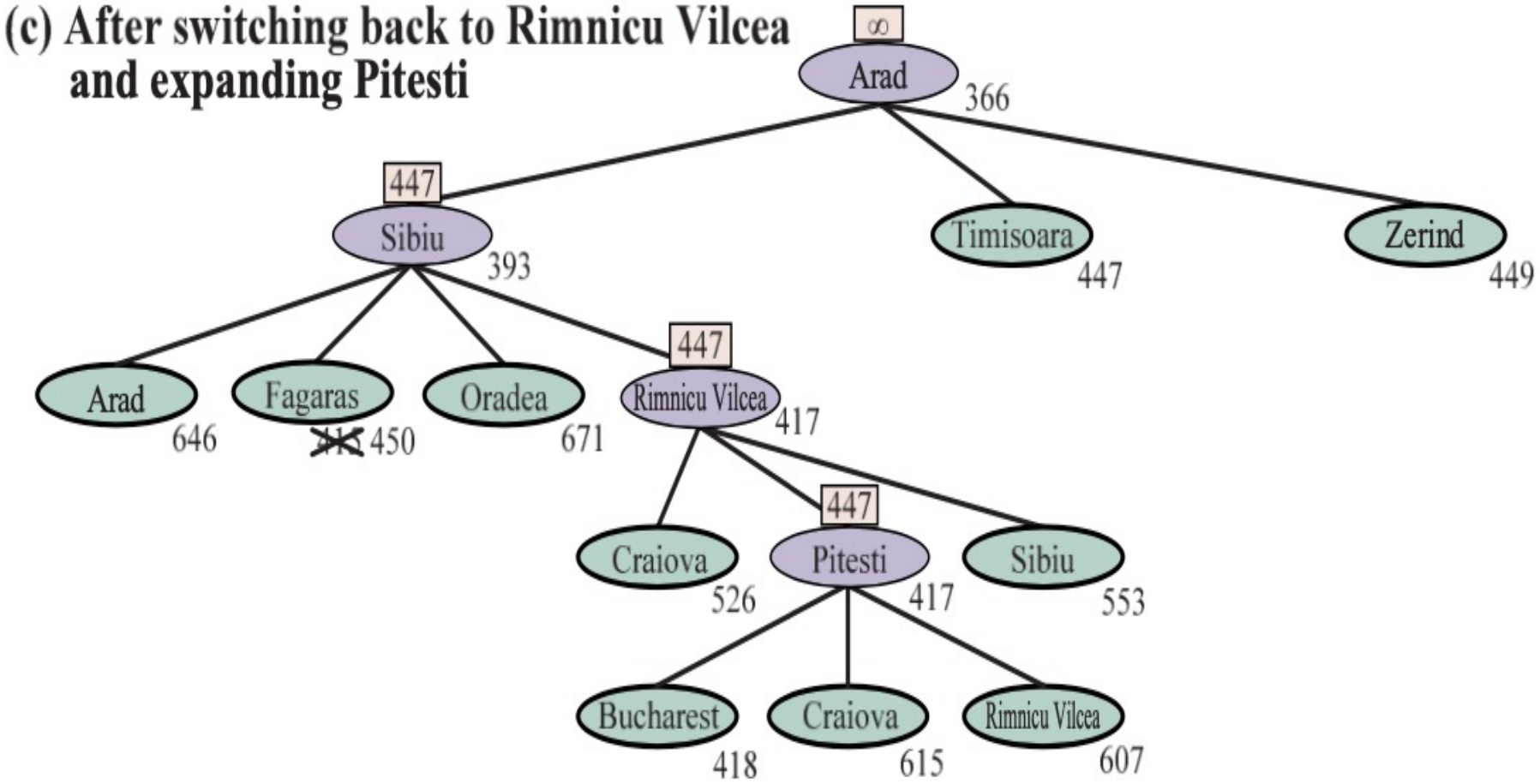
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Recursive Best-First Search (RBFS)



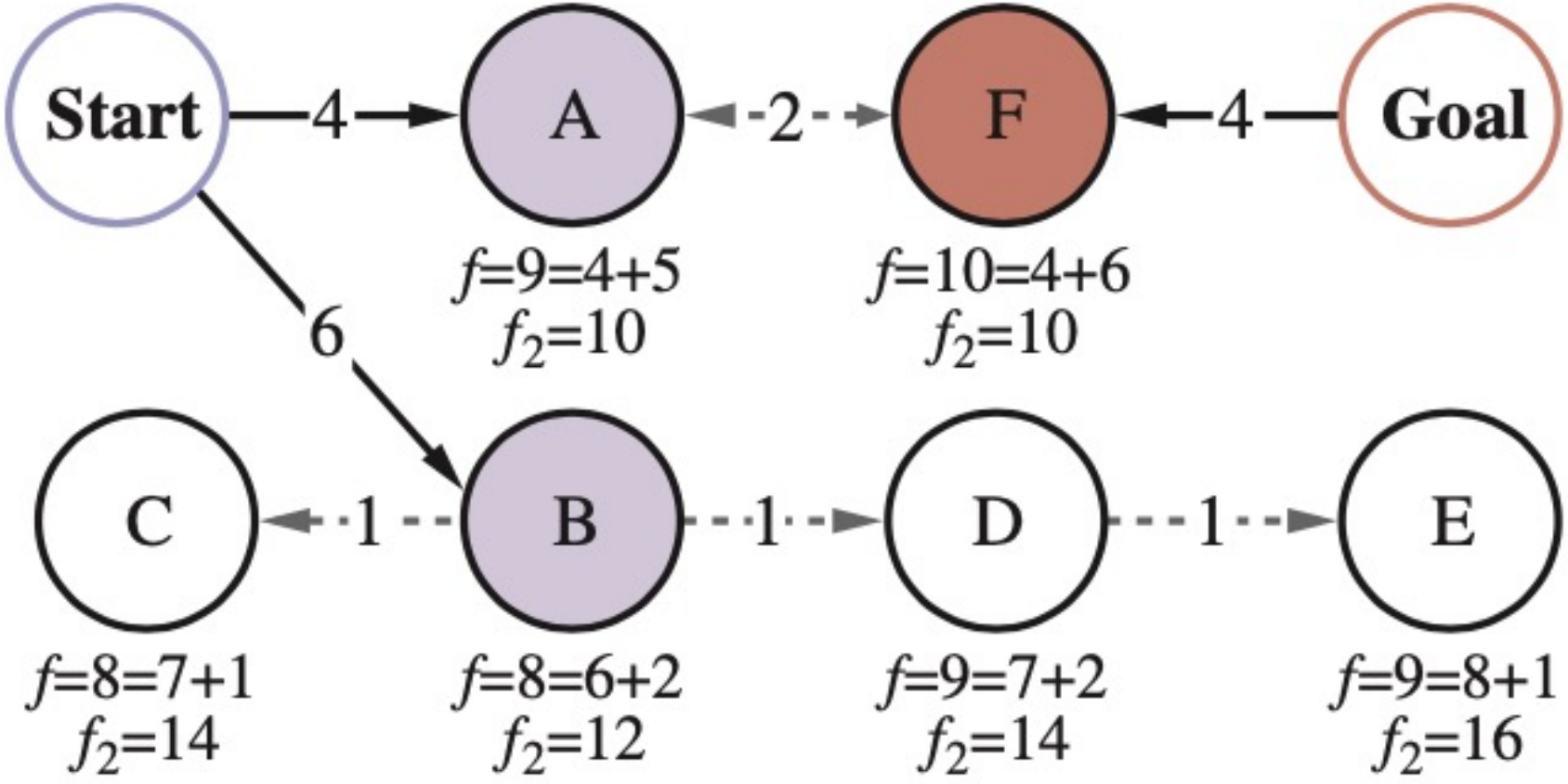
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Recursive Best-First Search (RBFS)



Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Bidirectional Search maintains two frontiers

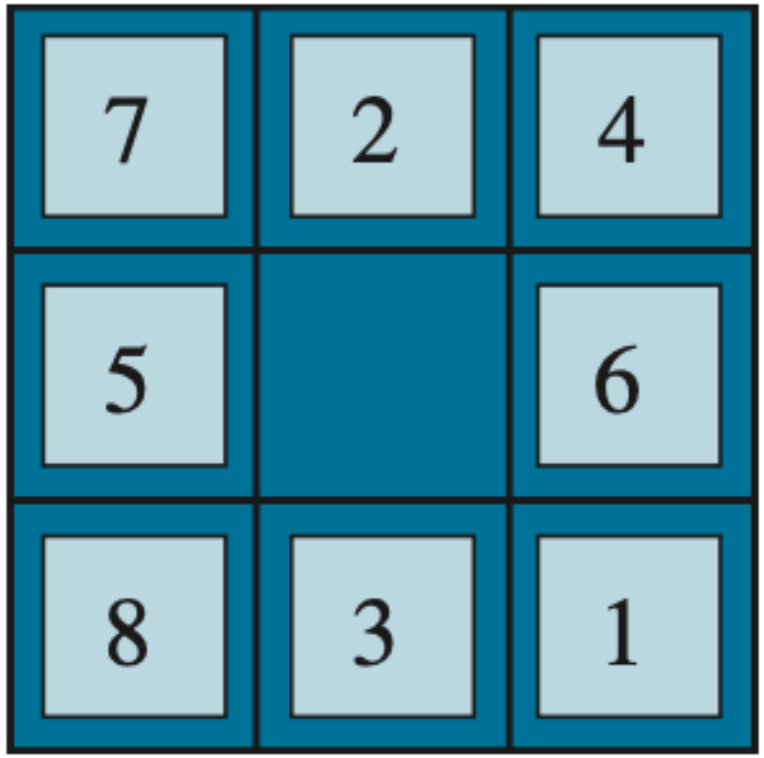


On the left, nodes A and B are successors of Start;
on the right, node F is an inverse successor of Goal

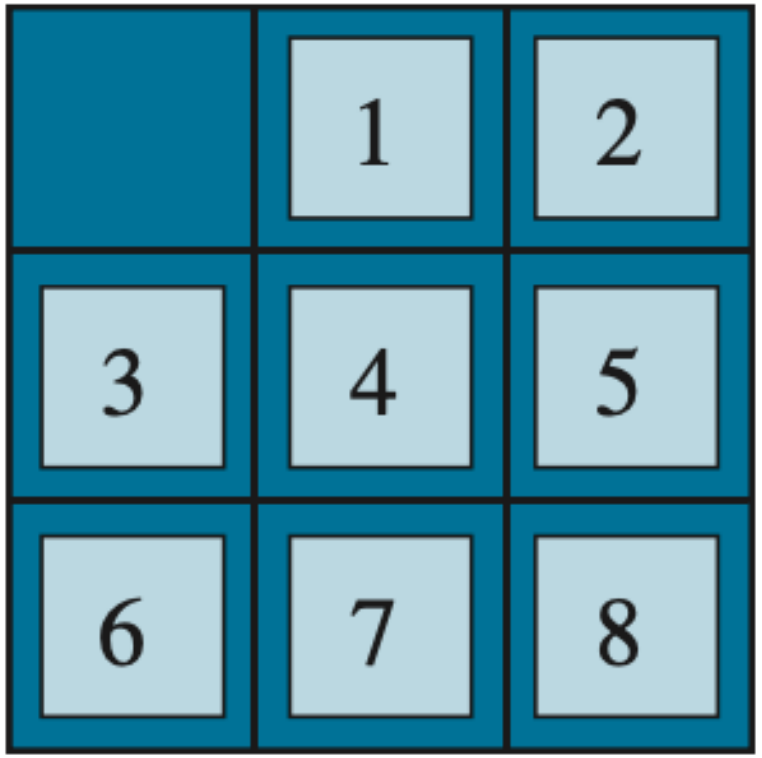
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A typical instance of the 8-puzzle

The shortest solution is 26 actions long



Start State



Goal State

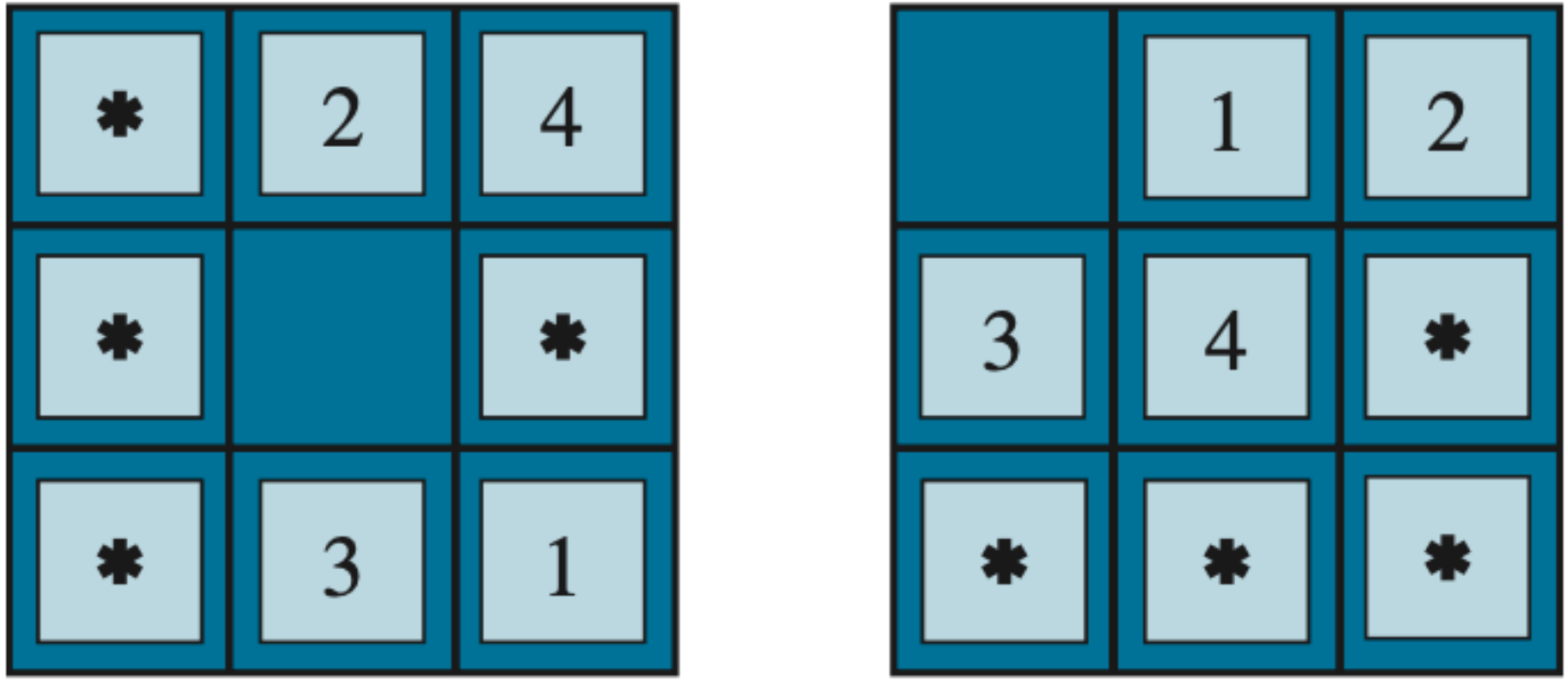
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Comparison of the search costs and effective branching factors for 8-puzzle problems

	Search Cost (nodes generated)			Effective Branching Factor		
d	BFS	A*(h_1)	A*(h_2)	BFS	A*(h_1)	A*(h_2)
6	128	24	19	2.01	1.42	1.34
8	368	48	31	1.91	1.40	1.30
10	1033	116	48	1.85	1.43	1.27
12	2672	279	84	1.80	1.45	1.28
14	6783	678	174	1.77	1.47	1.31
16	17270	1683	364	1.74	1.48	1.32
18	41558	4102	751	1.72	1.49	1.34
20	91493	9905	1318	1.69	1.50	1.34
22	175921	22955	2548	1.66	1.50	1.34
24	290082	53039	5733	1.62	1.50	1.36
26	395355	110372	10080	1.58	1.50	1.35
28	463234	202565	22055	1.53	1.49	1.36

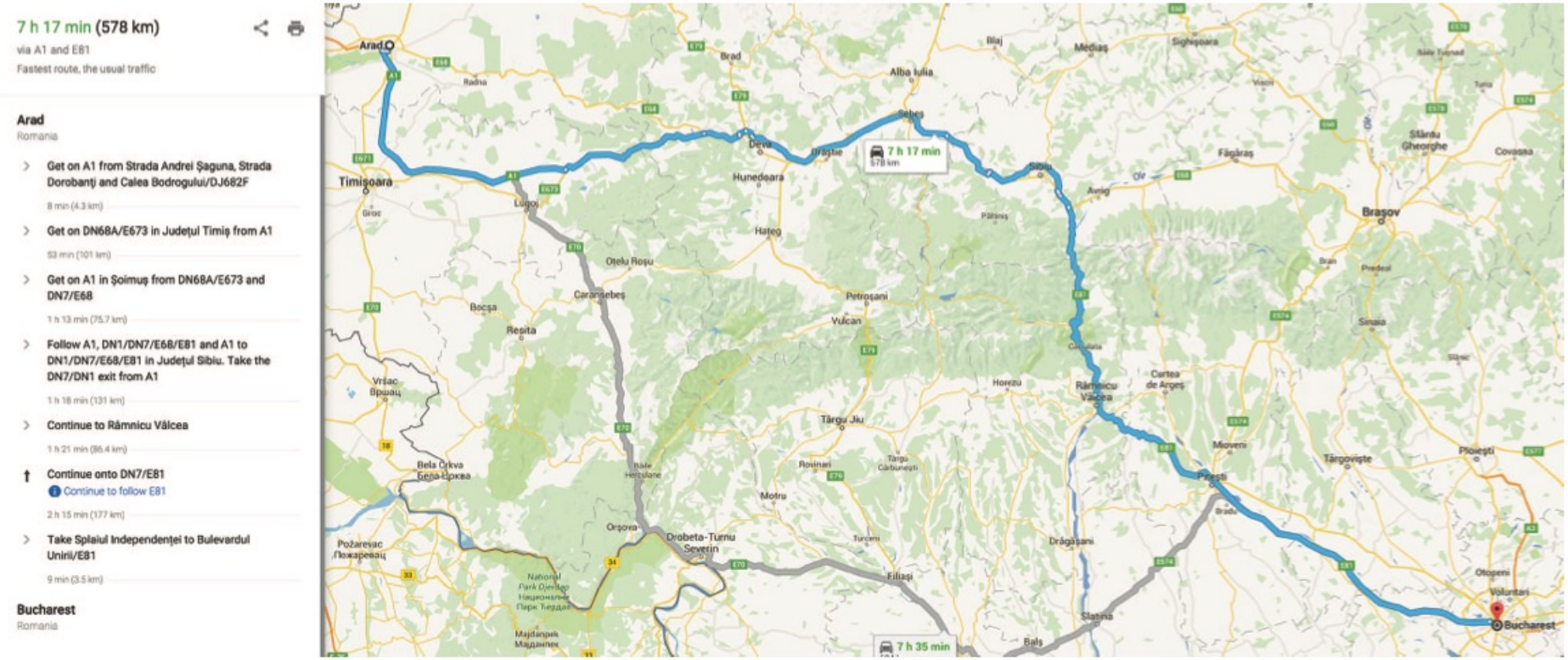
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

A subproblem of the 8-puzzle



The task is to get tiles 1, 2, 3, 4, and the blank into their correct positions, without worrying about what happens to the other tiles

A Web service providing driving directions, computed by a search algorithm.



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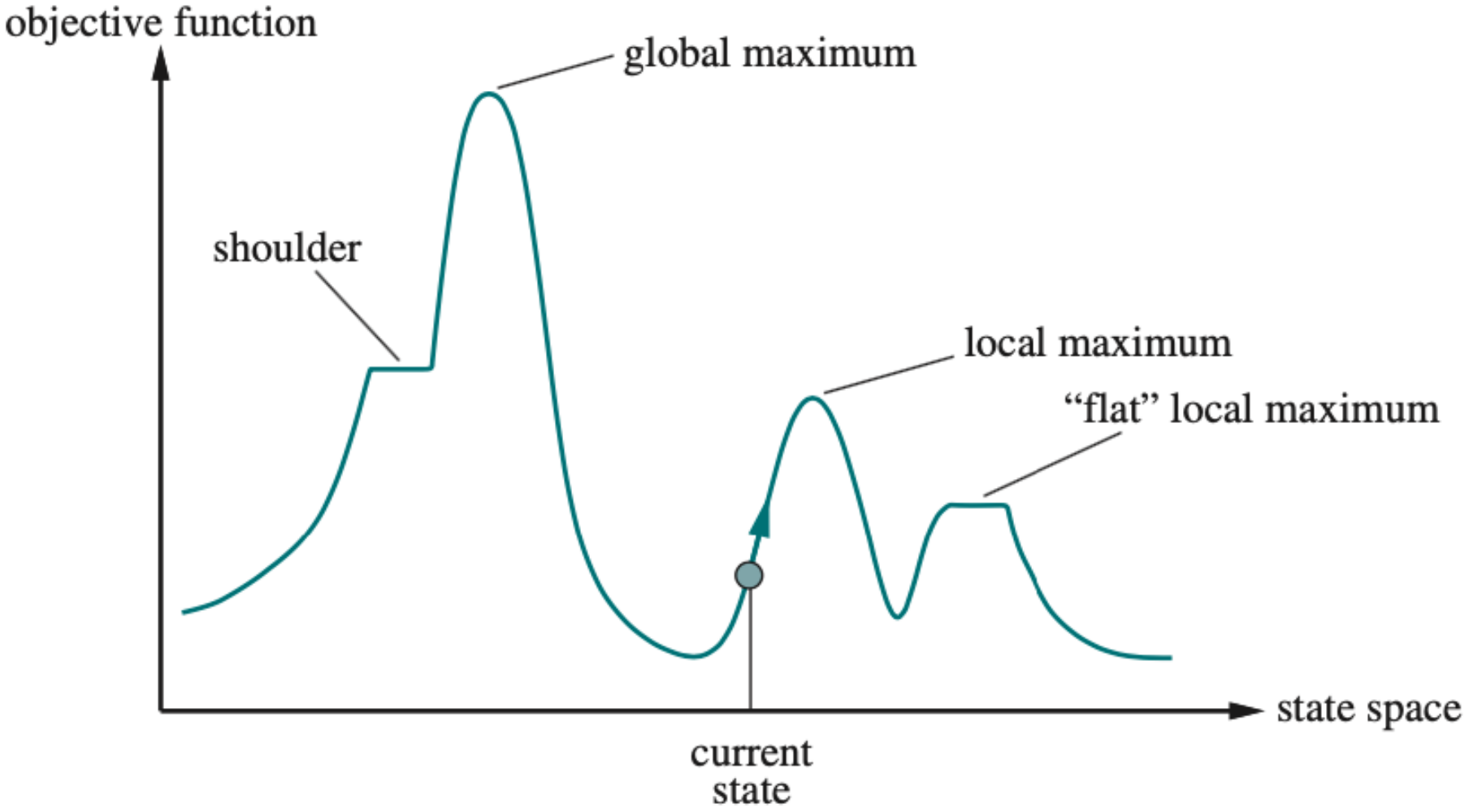
Search in Complex Environments

A one-dimensional state-space landscape



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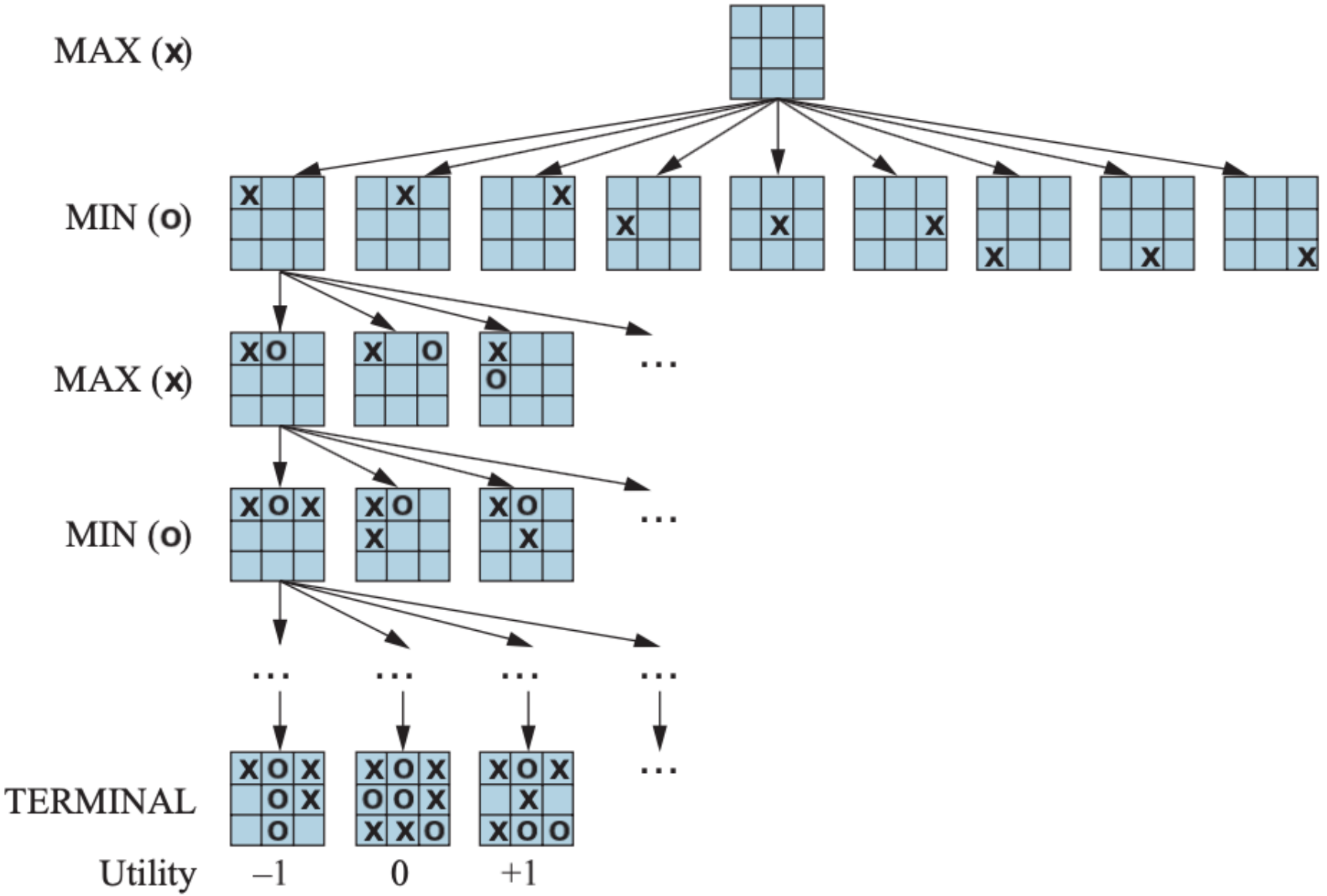
Adversarial Search and Games

Game Tree for the Game of Tic-tac-toe



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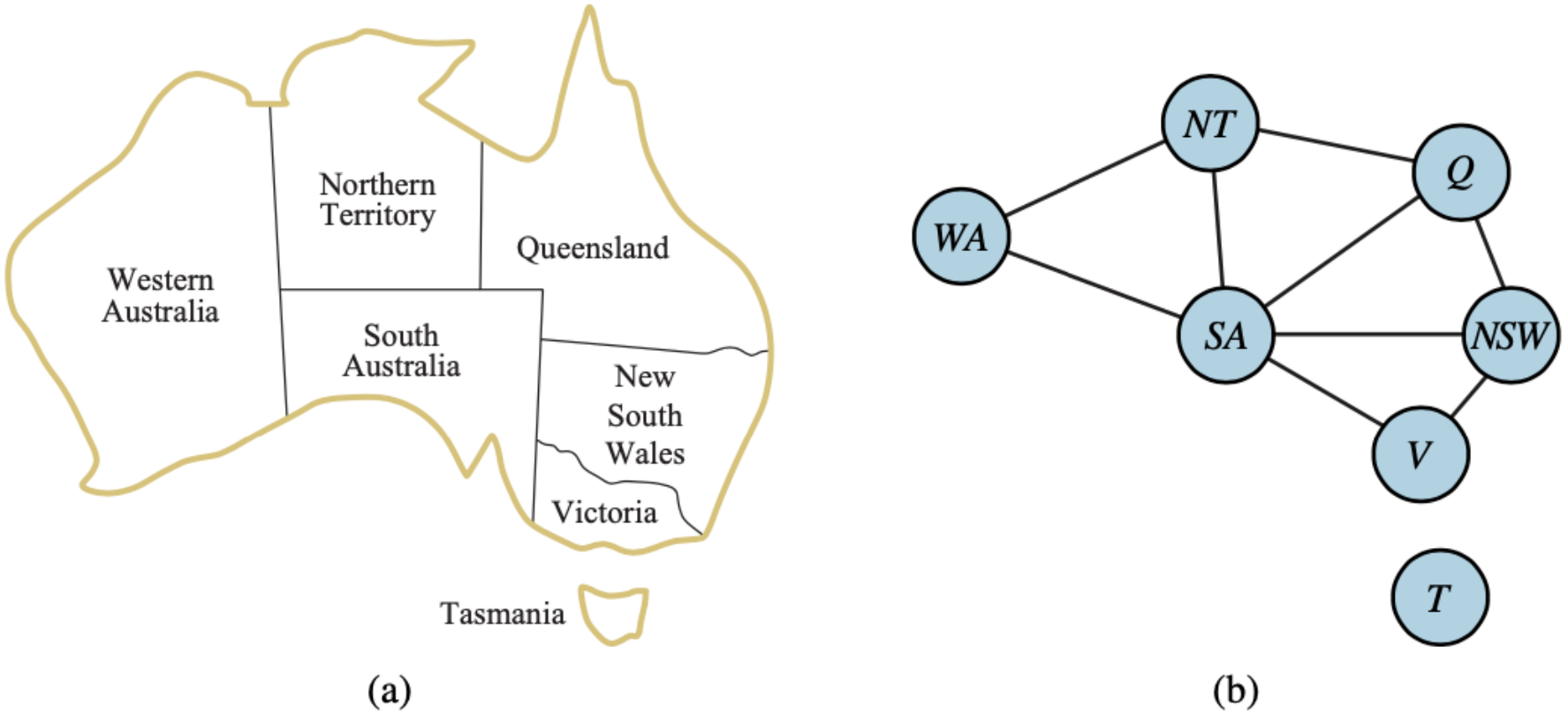
Constraint Satisfaction Problems

The Map-Coloring Problem Represented as a Constraint Graph



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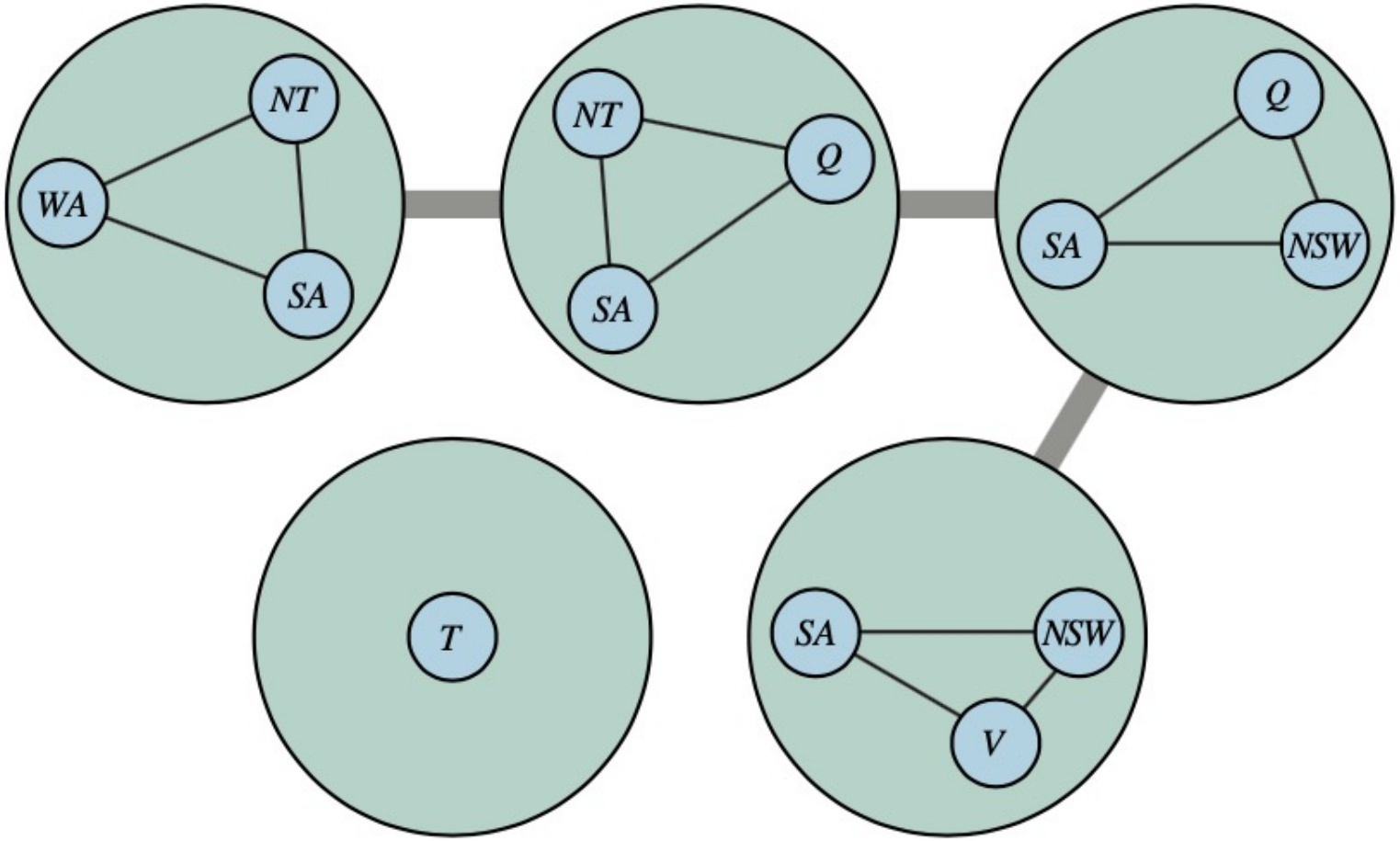
A Tree Decomposition of the Constraint Graph



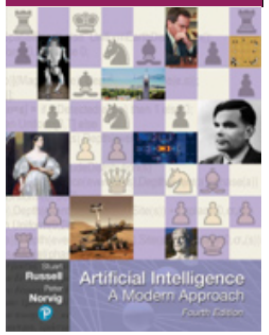
Source: Stuart Russell and Peter Norvig (2020), Artificial Intelligence: A Modern Approach, 4th Edition, Pearson

Artificial Intelligence: A Modern Approach (AIMA)

- **Artificial Intelligence: A Modern Approach (AIMA)**
  - http://aima.cs.berkeley.edu/
- **AIMA Python**
  - http://aima.cs.berkeley.edu/python/readme.html
  - https://github.com/aimacode/aima-python
- **Search**
  - http://aima.cs.berkeley.edu/python/search.html
- **Games: Adversarial Search**

  http://aima.cs.berkeley.edu/python/games.html
- **CSP (Constraint Satisfaction Problems)**
  - http://aima.cs.berkeley.edu/python/csp.html

Artificial Intelligence: A Modern Approach (AIMA)



Artificial Intelligence: A Modern Approach, 4th US ed.

by Stuart Russell and Peter Norvig

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http://aima.cs.berkeley.edu/

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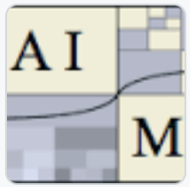

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Code for the book "Artificial Intelligence: A Modern Approach"

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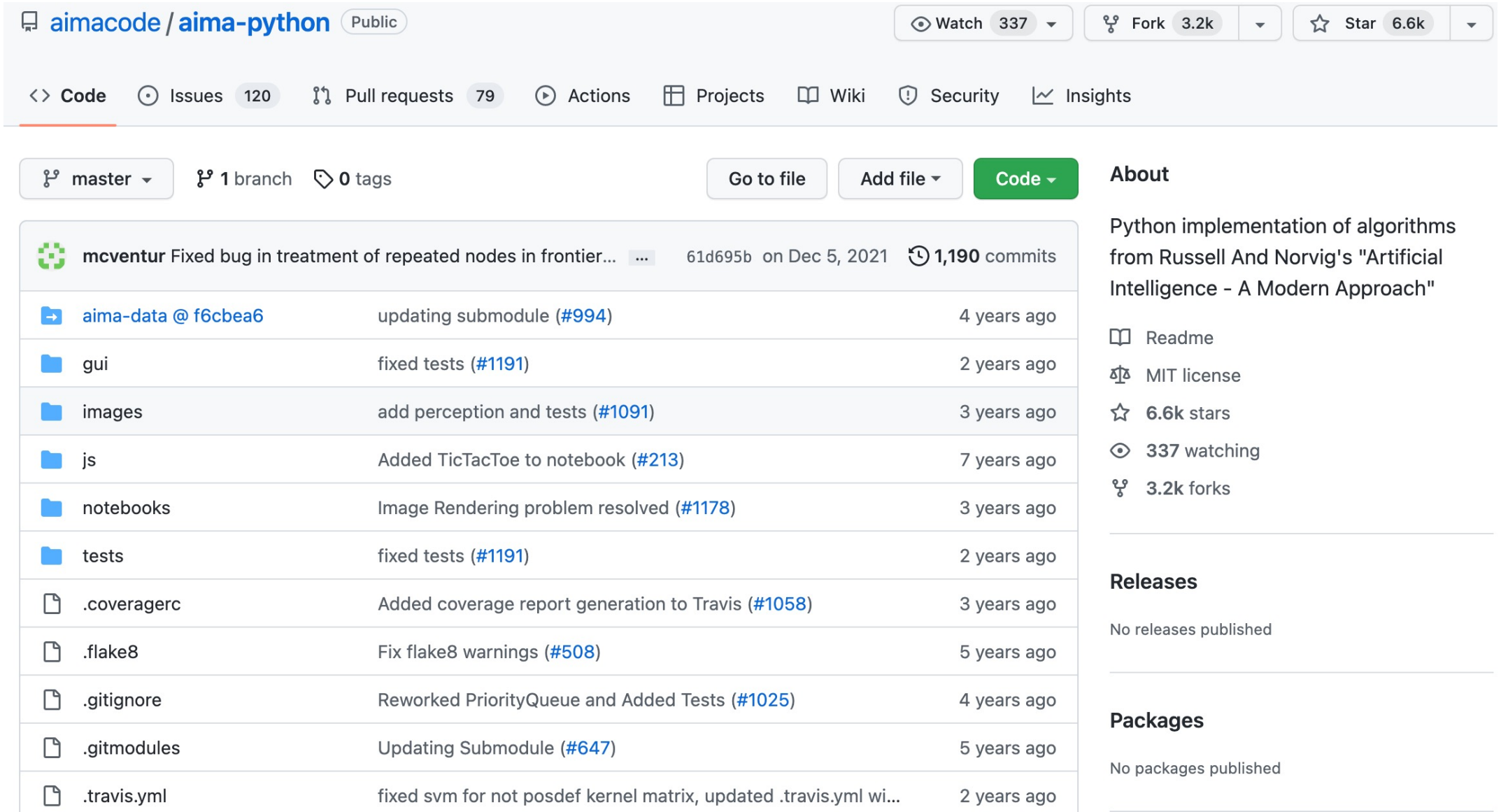
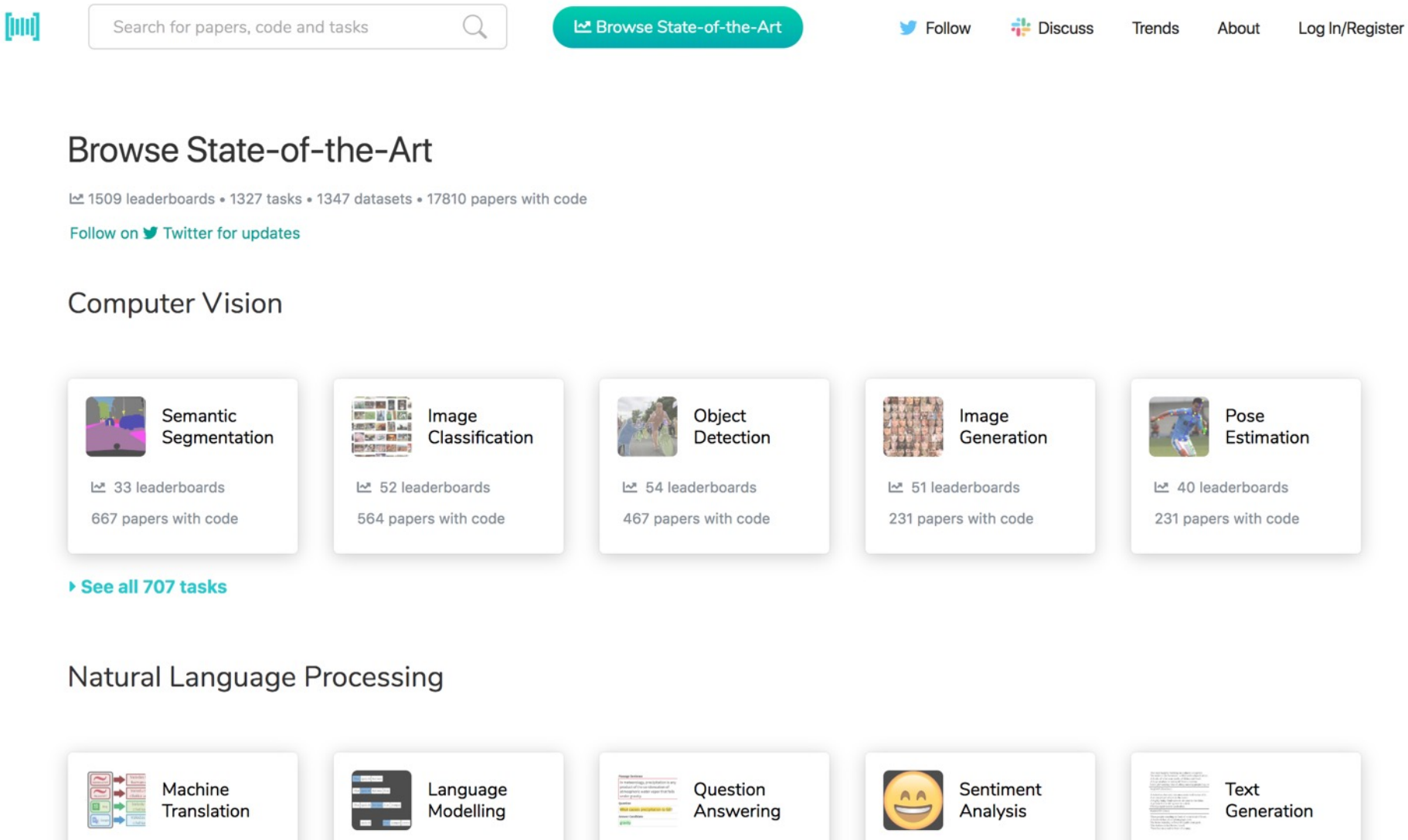
AIMA Python



https://github.com/aimacode/aima-python

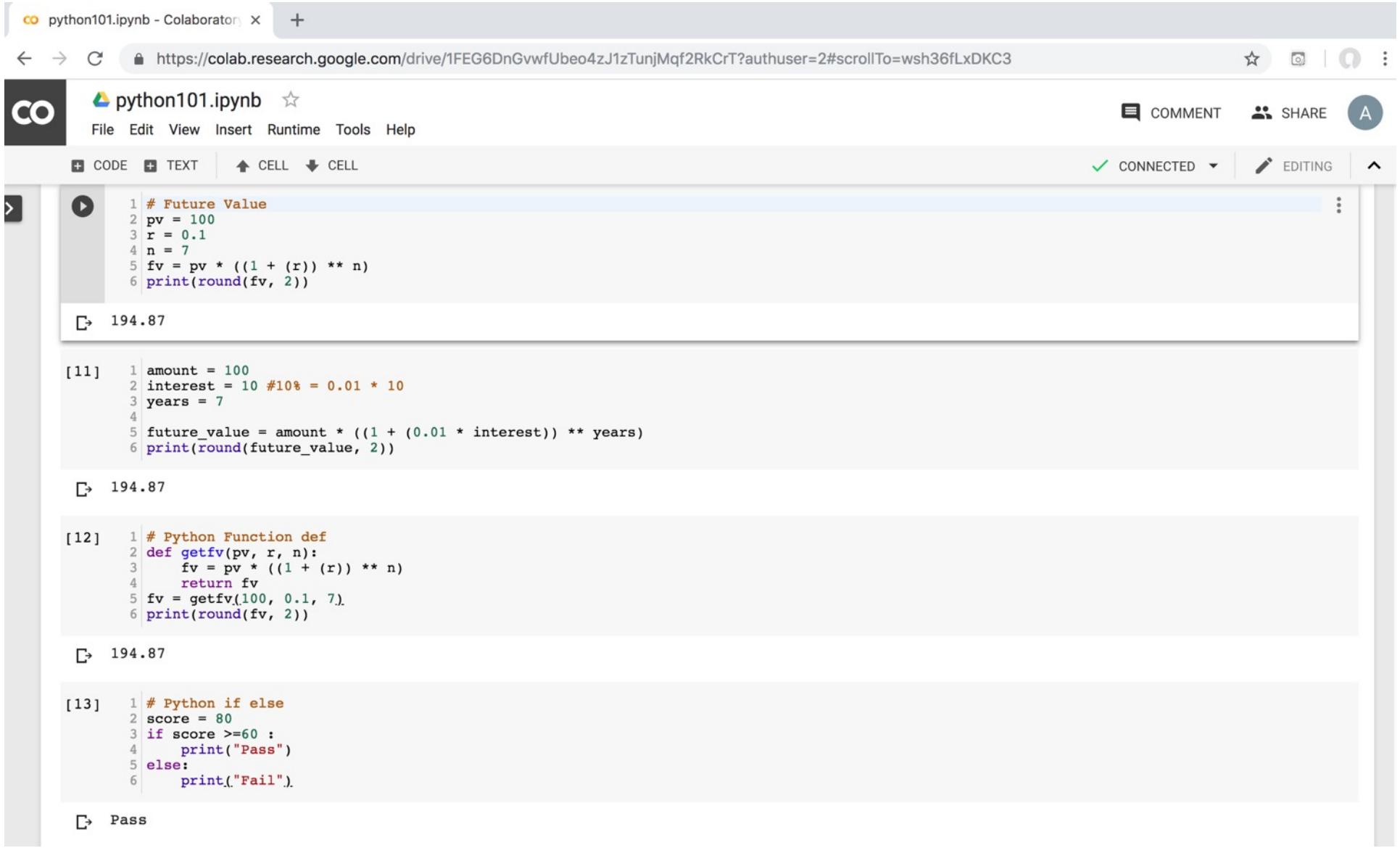
Papers with Code
State-of-the-Art (SOTA)



https://paperswithcode.com/sota

Python in Google Colab (Python101)

https://colab.research.google.com/drive/1FEG6DnGvwfUbeo4zJ1zTunjMqf2RkCrT



https://tinyurl.com/aintpupython101

Summary

- **Artificial Intelligence**
- **Intelligent Agents**
- **Problem Solving**

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