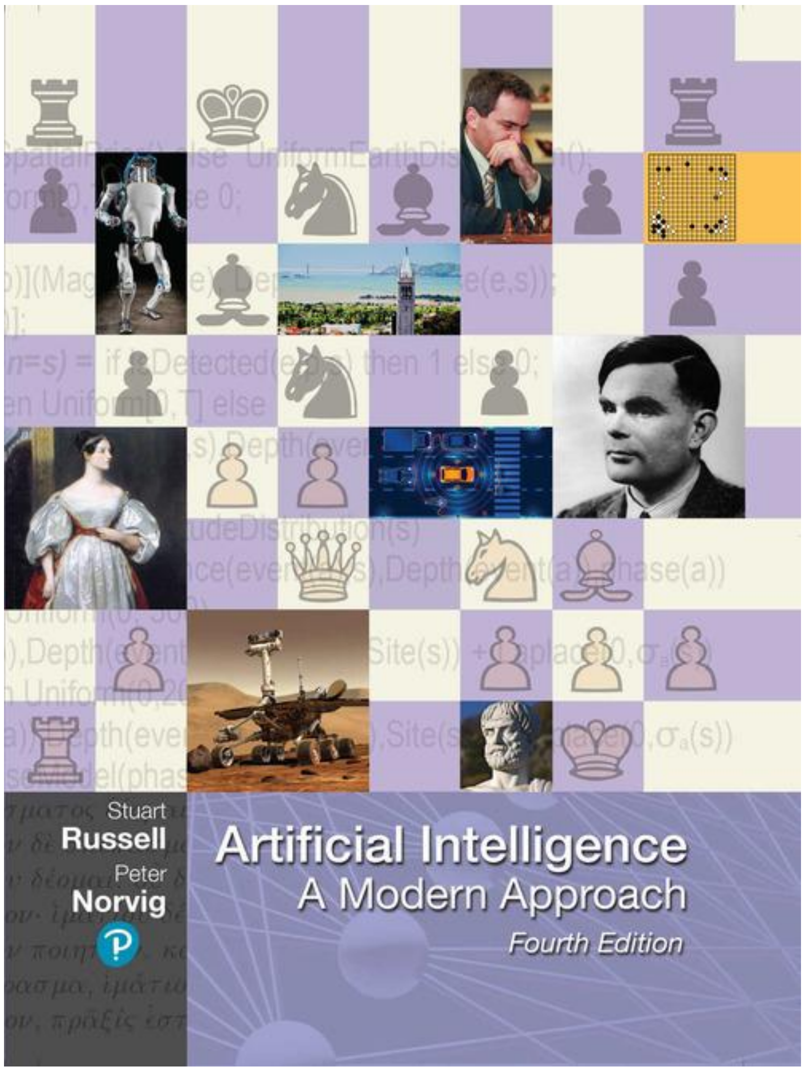
Artificial Intelligence: A Modern Approach

Fourth Edition



Chapter 23

Natural Language Processing

Human Languages

- The complexity and diversity of human languages set humans apart from all other species.

- When Alan Turing proposed his test for intelligence, he based it on language, perhaps because of its universal scope and because language captures so much of intelligent behavior:
  - a speaker (or writer)
  - has the **goal** of communicating some
  - **knowledge**, then
  - **plans** some language
  - that **represents** the knowledge,
  - and **acts** to achieve the goal.

Human Languages

- The listener (or reader)
  - **perceives** the language,
  - and **infers** the intended meaning.

- This type of communication via language has allowed civilization to grow; it is our main means of passing along cultural, legal, scientific, and technological knowledge.

- There are three primary reasons for computers to do **natural language processing (NLP)**:

  1. To **communicate** with humans. In many situations it is convenient for humans to use speech to interact with computers, and in most situations, it is more convenient to use natural language rather than a formal language such as first-order predicate calculus.

Human Languages

- There are three primary reasons for computers to do **natural language processing (NLP)**:

  2. To **learn**. Humans have written down a lot of knowledge using natural language. Wikipedia alone has 30 million pages whereas there are hardly any sources of facts like this written in formal logic. If we want our system to know a lot, it had better understand natural language.

  3. To advance the **scientific understanding** of languages and language use, using the tools of AI in conjunction with linguistics, cognitive psychology, and neuroscience.

Language Models

- Formal languages, such as first-order logic, are precisely defined.
- A **grammar** defines the syntax of legal sentences and **semantic rules** define the meaning.

- Natural languages, such as English, cannot be so neatly characterized:

- Natural language is **ambiguous** ("He saw her duck" can mean either that she owns a waterfowl, or that she made a downwards evasive move) and **vague** ("That's great!" does not specify precisely how great it is, nor what it is).

- The mapping from symbols to objects is not formally defined.
- In first-order logic, two uses of the symbol "Richard" must refer to the same person, but in natural language two occurrences of the same word or phrase may refer to different things in the world.

Language Models

- **Language model**: a probability distribution describing the likelihood of any string

- Such a model should say that “Do I dare disturb the universe?” has a reasonable probability as a string of English, but “Universe dare the I disturb do?” is extremely unlikely.

- With a language model, we can predict <u>what words are likely to come next</u> in a text, and thereby suggest completions for an email or text message.

- We can compute which alterations to a text would make it more probable, and thereby suggest spelling or grammar corrections.

- With a pair of models, we can compute <u>the most probable translation</u> of a sentence.

Language Models

- With some example question/answer pairs as training data, we can compute the most likely answer to a question.
- So, **language models** are at the heart of a broad range of natural language tasks.
- The language modeling task itself also serves as a common benchmark to measure progress in language understanding.

Language Models

- Natural languages are complex, so any language model will be, at best, an approximation.
- The linguist Edward Sapir said “No language is tyrannically consistent. All grammars leak” (Sapir, 1921).
- The philosopher Donald Davidson said “there is no such thing as language, not if a language is . . . a clearly defined shared structure” (Davidson, 1986), by which he meant there is no one definitive language model for English in the way that there is for Python; we all have different models, but we still somehow manage to muddle through and communicate.
- In this section we cover simplistic language models that are clearly wrong, but still manage to be useful for certain tasks.

Acting under uncertainty (Chapter 12)

- Agents in the real world need to handle **uncertainty**, whether due to partial observability, nondeterminism, or adversaries.

- An agent may never know for sure what state it is in now or where it will end up after a sequence of actions.

- Some logical agents handle uncertainty by keeping track of a **belief state.**

- **A belief state** is a representation of the set of all possible world states that it might be in—and generating a contingency plan that handles every possible eventuality that its sensors may report during execution. This approach works on simple problems, but it has its drawbacks.

Acting under uncertainty (Chapter 12)

Belief state drawbacks:

1. The agent must consider *every possible* explanation for its sensor observations, no matter how unlikely. This leads to a large belief-state full of unlikely possibilities.

2. A correct contingent plan that handles every eventuality can grow arbitrarily large and must consider arbitrarily unlikely contingencies.

3. Sometimes there is no plan that is guaranteed to achieve the goal—yet the agent must act. It must have some way to compare the merits of plans that are not guaranteed.

Acting Under Uncertainty

- Real world problems contain **uncertainties due to:**
  - partial observability,
  - nondeterminism, or
  - adversaries.

- Example of dental diagnosis using propositional logic

$$Toothache \Rightarrow Cavity.$$

- However inaccurate, not all patients with toothaches have cavities

$$Toothache \Rightarrow Cavity \lor GumProblem \lor Abscess \ldots$$

- In order to make the rule true, we have to add an almost unlimited list of possible problems.

- The only way to fix the rule is to make it logically exhaustive

Acting Under Uncertainty

- An agent strives to choose the right thing to do—the rational decision—depends on both the relative importance of various goals and the likelihood that, and degree to which, they will be achieved.

- Large domains such as medical diagnosis fail to three main reasons:
  - **Laziness:** It is too much work to list the complete set of antecedents or consequents needed to ensure an exceptionless rule

  - **Theoretical ignorance:** Medical science has no complete theory for the domain

  - **Practical ignorance:** Even if we know all the rules, we might be uncertain about a particular patient because not all the necessary tests have been or can be run.

- An agent only has a degree of belief in the relevant sentences.

Acting Under Uncertainty

- The connection between toothaches and cavities <u>is not a strict logical consequence in either direction</u>.

- This is typical of the medical domain, as well as most other judgmental domains: law, business, design, automobile repair, gardening, dating, and so on.

- The agent's knowledge can at best provide only a **degree of belief** in the relevant sentences.

- Our main tool for dealing with degrees of belief is **probability theory**.

- A probabilistic agent may have a numerical degree of belief between 0 (for sentences that are certainly false) and 1 (certainly true).

Acting Under Uncertainty

- The theory of *probability provides a way of summarizing the uncertainty that comes from our **laziness** and **ignorance***, thereby solving the qualification problem.

- We might not know for sure what afflicts a particular patient, but we believe that there is, say, an 80% chance—that is, a probability of 0.8—that the patient who has a toothache has a cavity.

- That is, we expect that out of all the situations that are indistinguishable from the current situation as far as our knowledge goes, the patient will have a cavity in 80% of them.

- This belief could be derived from statistical data—80% of the toothache patients seen so far have had cavities—or from some general dental knowledge, or from a combination of evidence sources.

Acting Under Uncertainty

- One confusing point is that at the time of our diagnosis, there is no uncertainty in the actual world: the patient either has a cavity or doesn’t.

- So what does it mean to say the probability of a cavity is 0.8? Shouldn’t it be either 0 or 1? The answer is that probability statements are **made with respect to a knowledge state**, not with respect to the real world.

- We say “The probability that the patient has a cavity, *given that she has a toothache*, is 0.8.”

- If we later learn that the patient has a history of gum disease, we can make a different statement: “The probability that the patient has a cavity, given that she has a toothache and a history of gum disease, is 0.4.”

Acting Under Uncertainty

- If we gather further conclusive evidence against a cavity, we can say "The probability that the patient has a cavity, given all we now know, is almost 0."

- Note that these statements do not contradict each other; each is a separate assertion about a different knowledge state.

Acting Under Uncertainty

- Consider an agent whose task is to plan your trip to the airport to catch a flight.
  - leave 30 mins before flight departure time?
  - leave 2 hours before?
  - Leave 24 hour before?!

- To make such choices, an agent must first have **preferences** among the different possible **outcomes** of the various plans.

- <u>An outcome is a completely specified state</u>, including such factors as whether the agent arrives on time and the length of the wait at the airport.

Acting Under Uncertainty

- We use **utility theory** to represent preferences and reason quantitatively with them. (The term **utility** is used here in the sense of "the quality of being useful," not in the sense of the electric company or water works.)

- Utility theory says that every state (or state sequence) has a degree of usefulness, or utility, to an agent and that the **agent will prefer states with higher utility.**

- The utility of a state is relative to an agent. For example, the utility of a state in which White has checkmated Black in a game of chess is obviously high for the agent playing White, but low for the agent playing Black.

Acting Under Uncertainty

- Preferences, as expressed by utilities, are combined with probabilities in the general theory of rational decisions called **decision theory**:

$$Decision\ \ theory = probability\ \ theory + utility\ \ theory.$$

- The fundamental idea of decision theory is that *an agent is rational if and only if it chooses the action that yields the highest expected utility, averaged over all the possible outcomes of the action.*

- This is called the principle of **maximum expected utility (MEU)**.

- Here, "expected" means the "average," or "statistical mean" of the outcome utilities, weighted by the probability of the outcome.

Bayes thinking

- Video time ☺
- Bayes thinking

https://www.youtube.com/watch?v=BrK7X_XlGB8&t=343s

- Multinomial Naïve Bayes Classifier

https://www.youtube.com/watch?v=O2L2Uv9pdDA