Informed Search

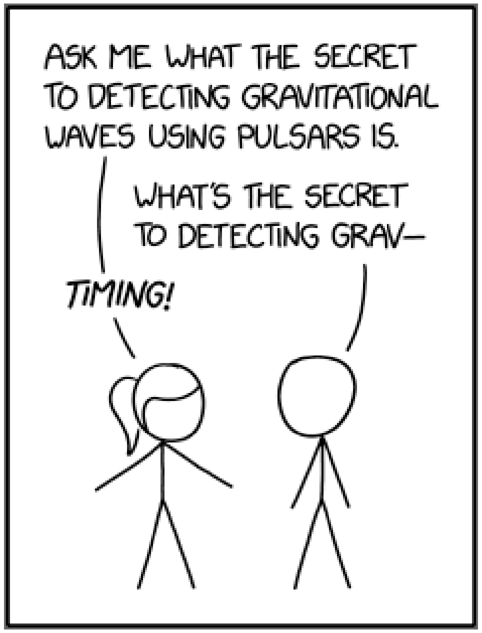
CS5491: Artificial Intelligence
ZHICHAO LU

Content Credits: **Prof. Wei**'s CS4486 Course
and **Prof. Boddeti**'s AI Course

TODAY (PART 2)

Informed Search Methods

- Heuristics
- Greedy Search
- A^* Search



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Reading

- Today's Lecture: RN Chapter 3.5-3.6, 4.1-4.2

SEARCH PROBLEMS

Uninformed Search

Methods we saw:

- DFS
- BFS
- UCS

Searching with your **EYES CLOSED**

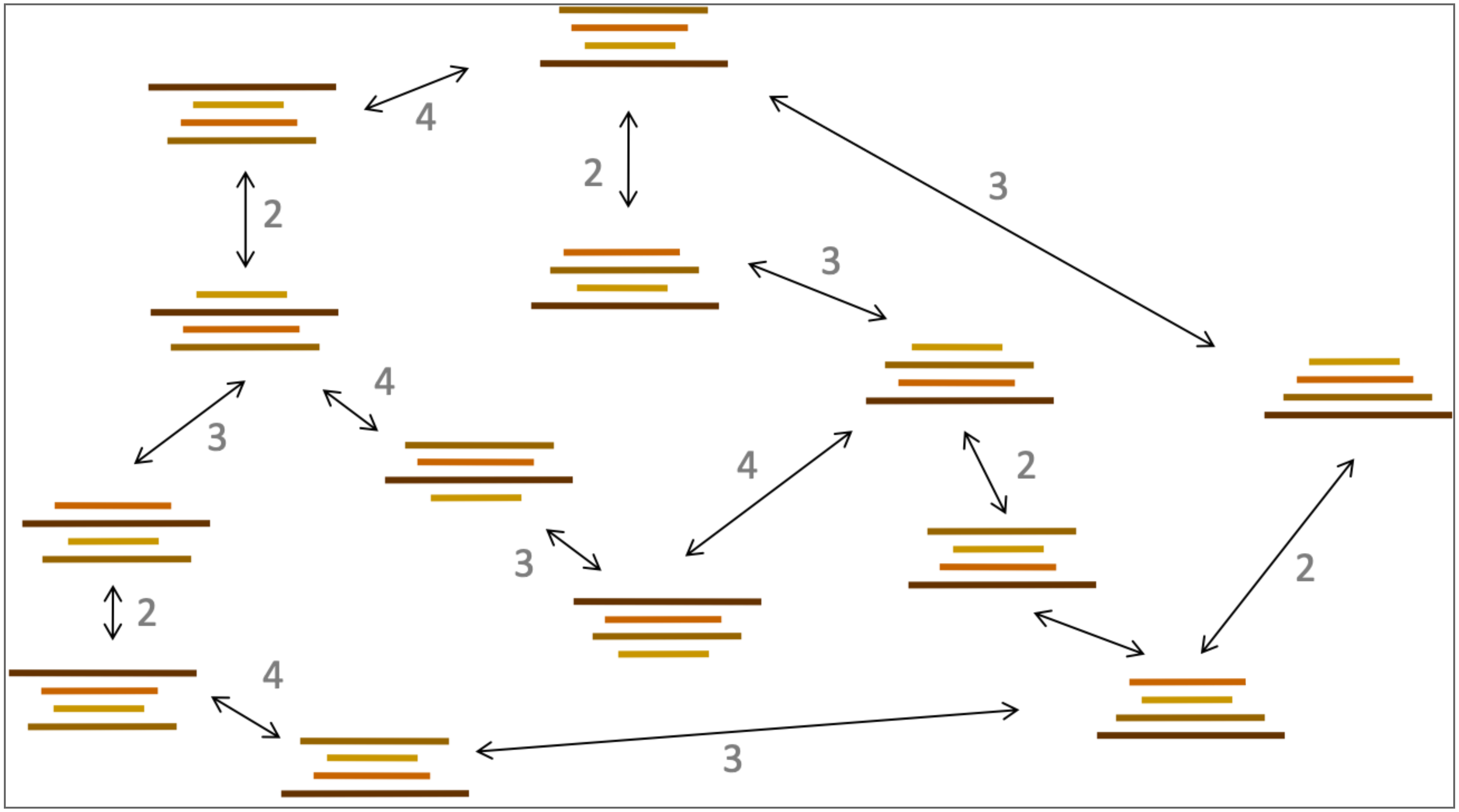
Informed Search

Methods we will see:

- Greedy
- A^*

Searching with your **EYES OPEN**

EXAMPLE: PANCAKE PROBLEM

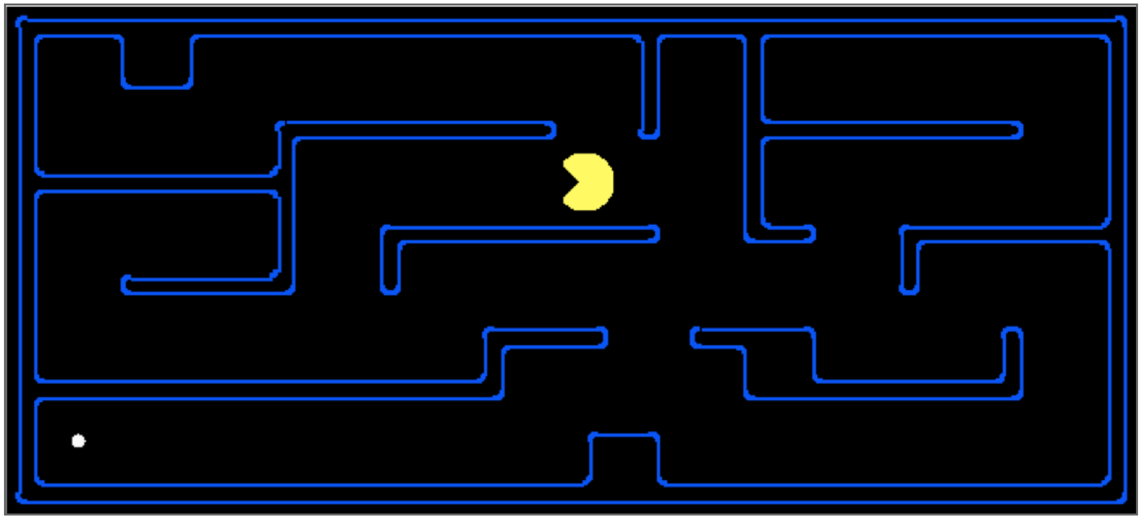


HEURISTICS

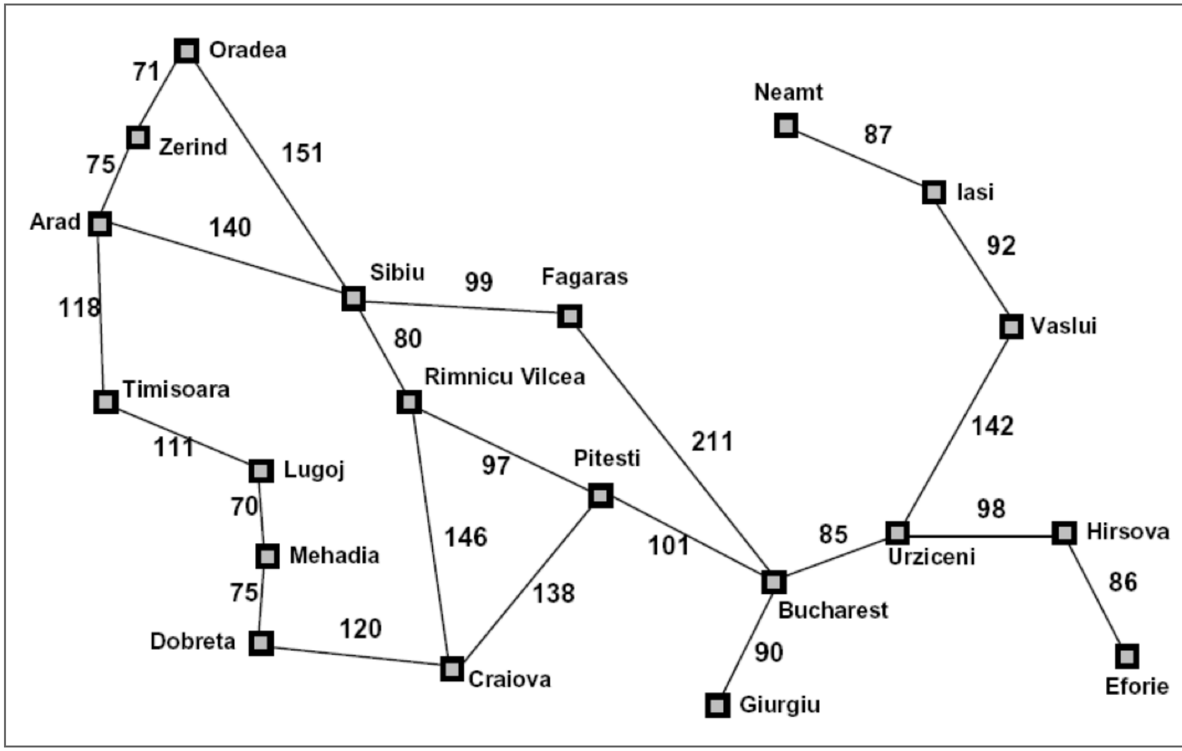
SEARCH HEURISTICS

A heuristic is:

- A function that estimates how close a state is to a goal
- Designed for a particular search problem
- Examples: Manhattan distance, Euclidean distance



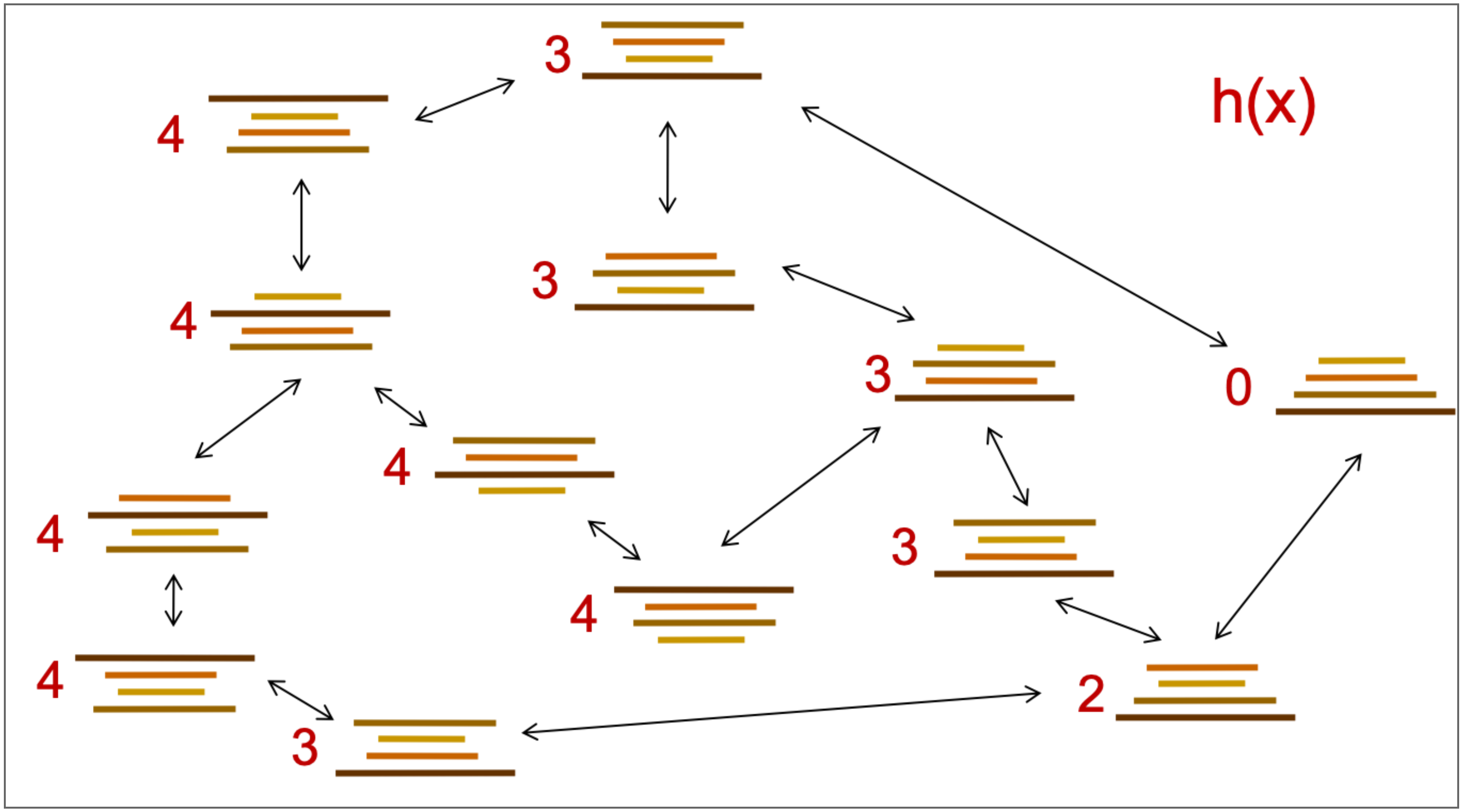
EXAMPLE: HEURISTIC FUNCTION



Straight−line distance to Bucharest	
Arad	366
Bucharest	0
Craiova	160
Dobreta	242
Eforie	161
Fagaras	178
Giurgiu	77
Hirsova	151
Iasi	226
Lugoj	244
Mehadia	241
Neamt	234
Oradea	380
Pitesti	98
Rimnicu Vilcea	193
Sibiu	253
Timisoara	329
Urziceni	80
Vaslui	199
Zerind	374

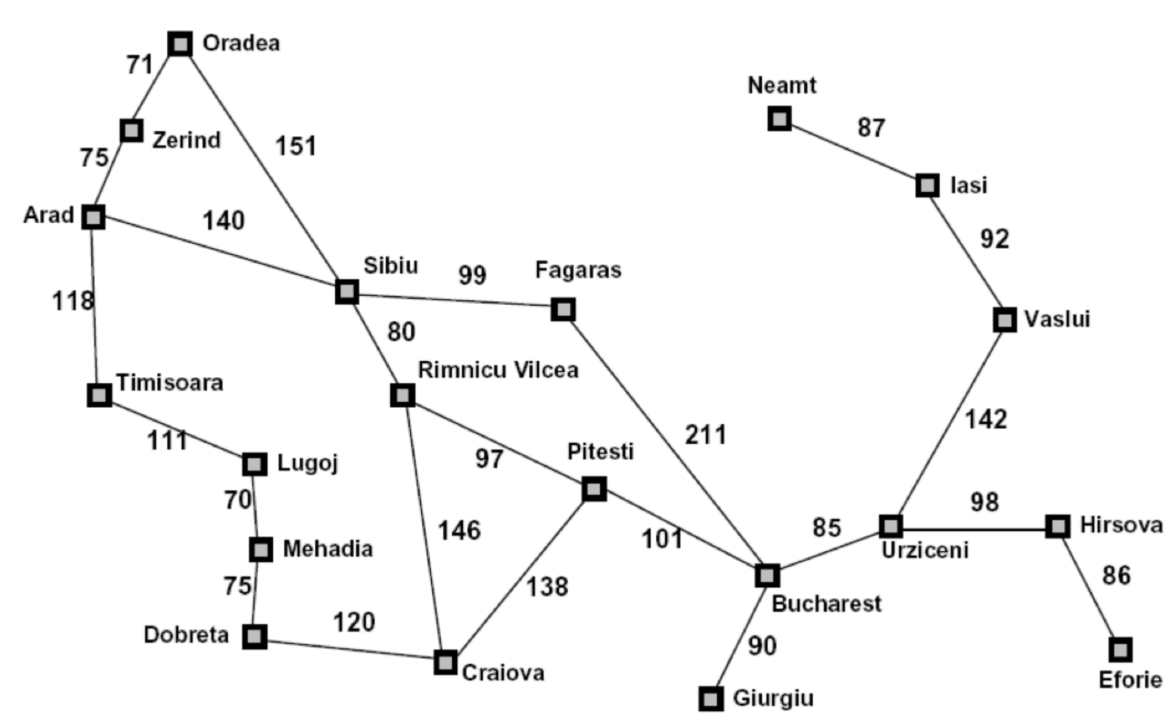
EXAMPLE: HEURISTIC FUNCTION

Eg: index of the largest pancake that is still out of place



GREEDY SEARCH

EXAMPLE: HEURISTIC FUNCTION



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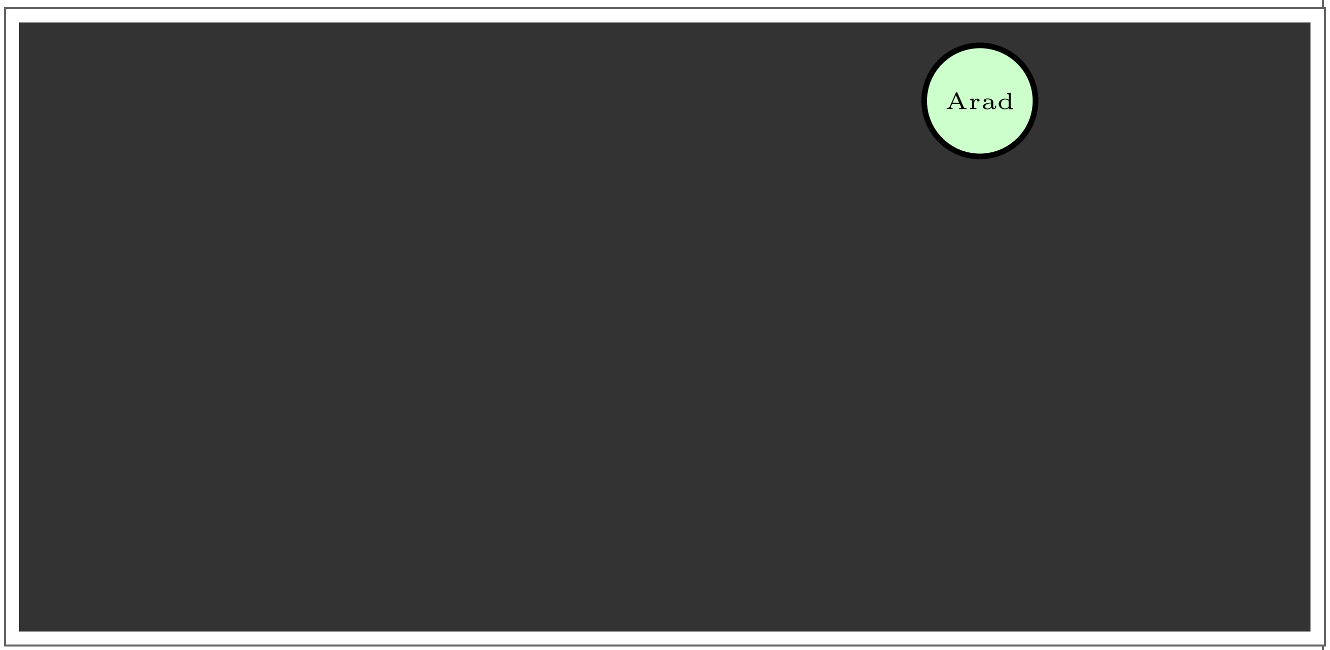
GREEDY SEARCH: ROMANIA

Expand the node that seems closest…



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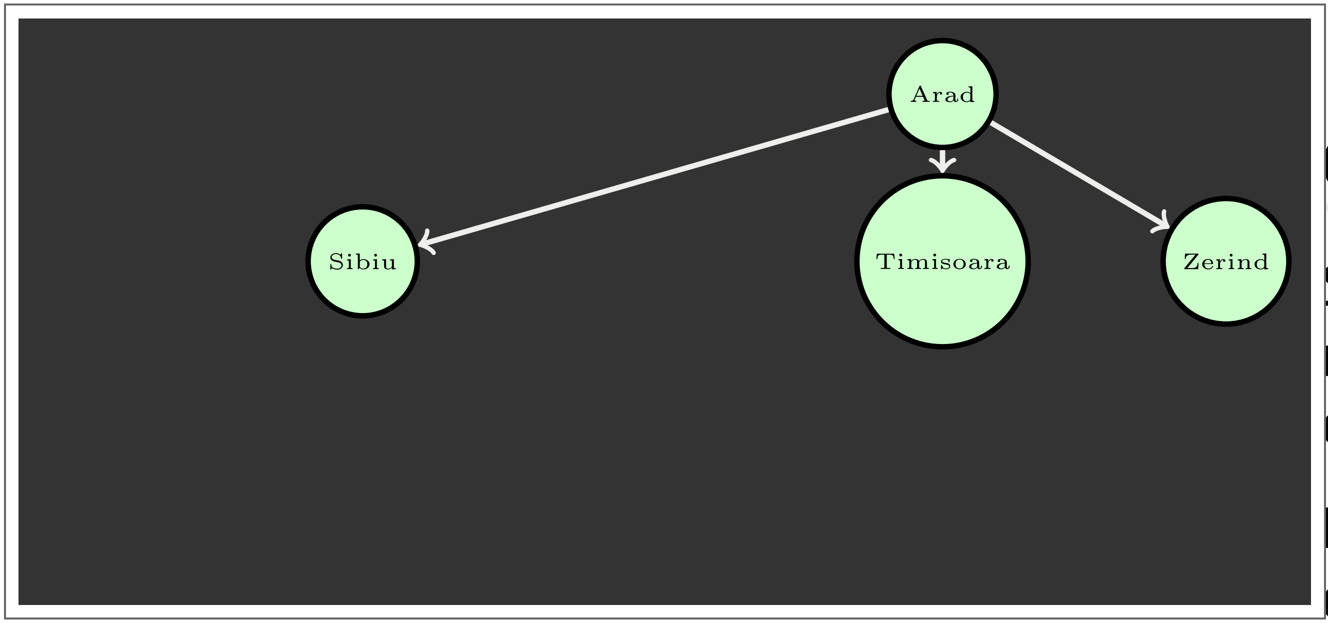
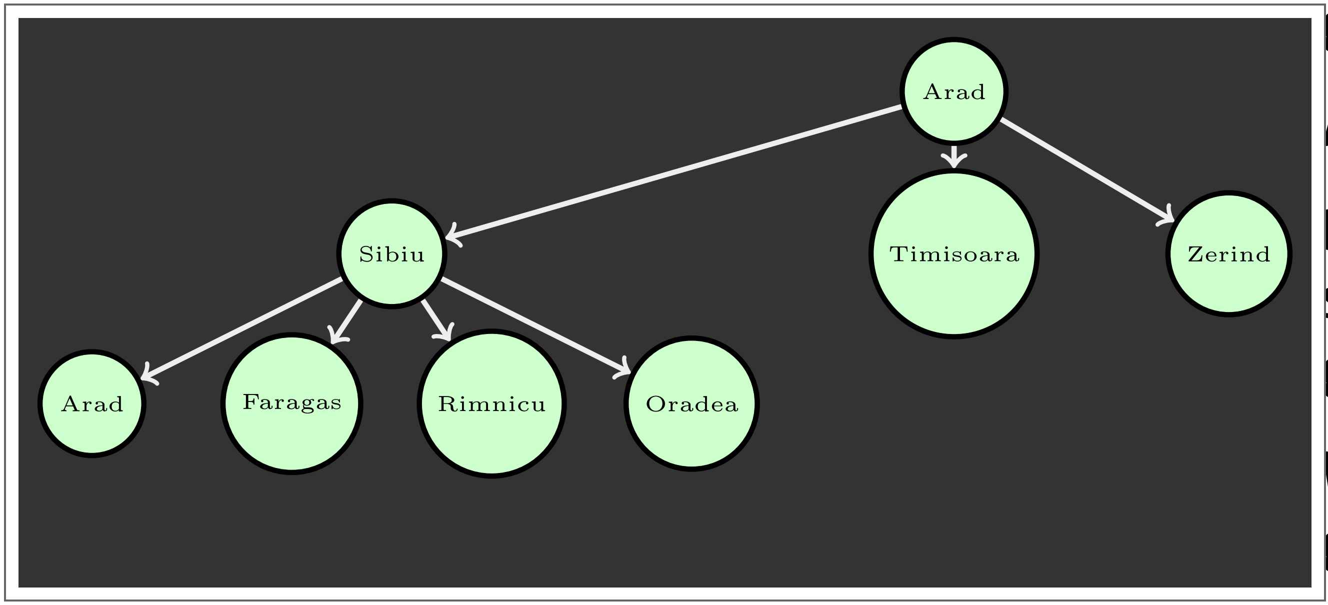




GREEDY SEARCH

Strategy: expand a node that you think is closest to a goal state

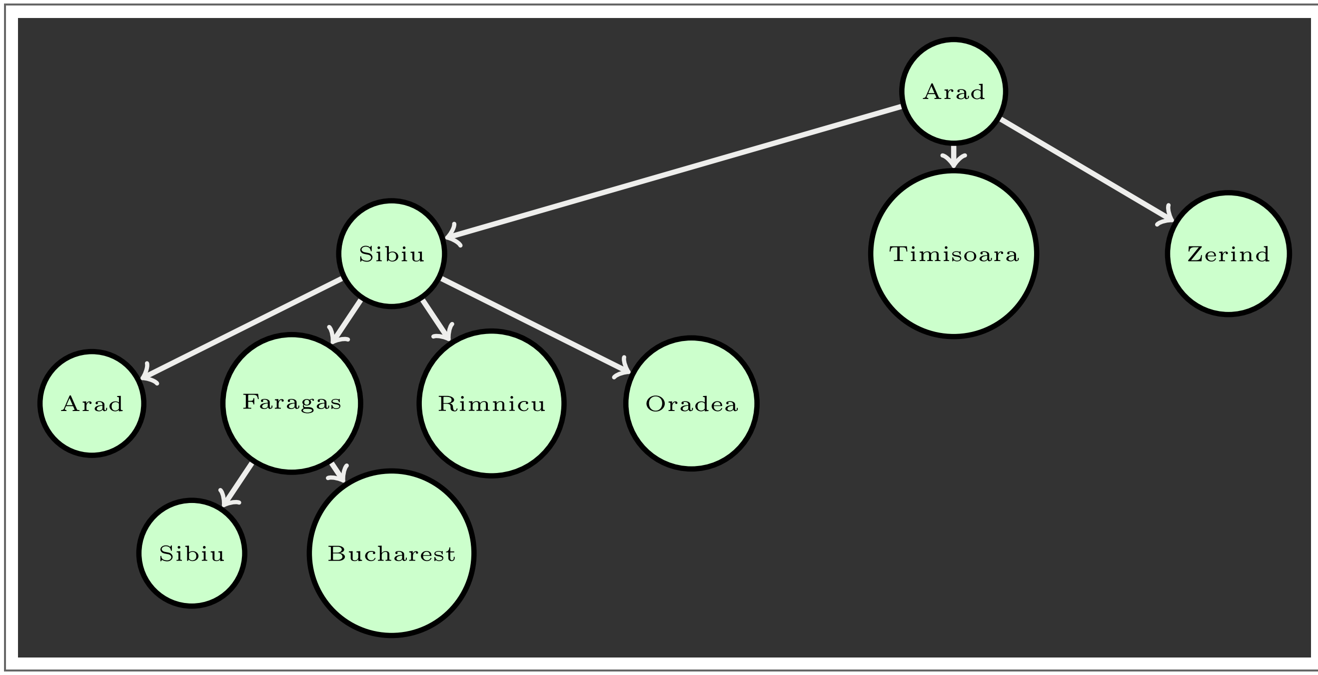
Heuristic: distance estimate to nearest goal for each state

A common case:

Best-first takes you straight to the (wrong) goal

Worst-case: like a badly-guided DFS

GREEDY DEMO



What can go wrong?

A^* SEARCH

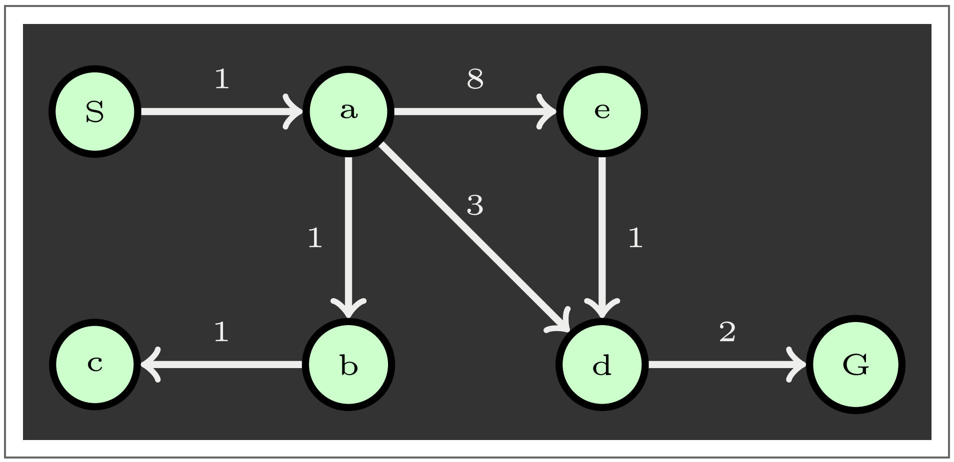
KEY IDEA: COMBINE UCS AND GREEDY

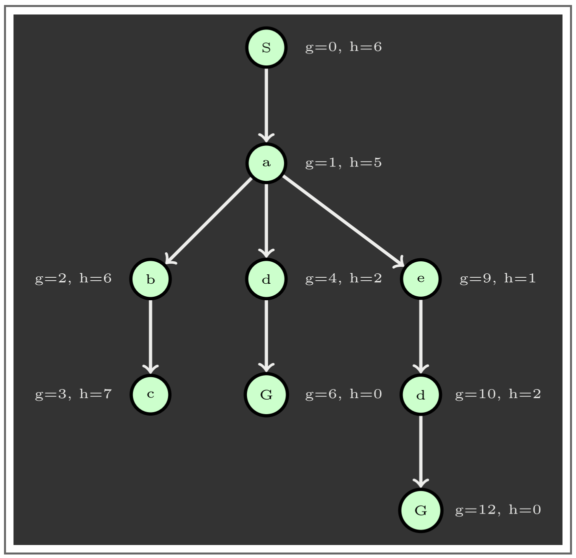
COMBINING UCS AND GREEDY

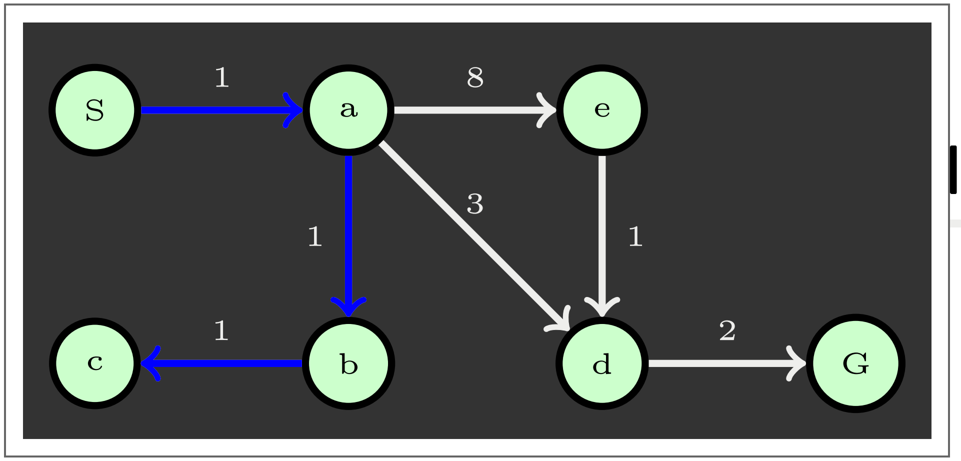
Uniform-cost orders by path cost, or backward cost $g(n)$.

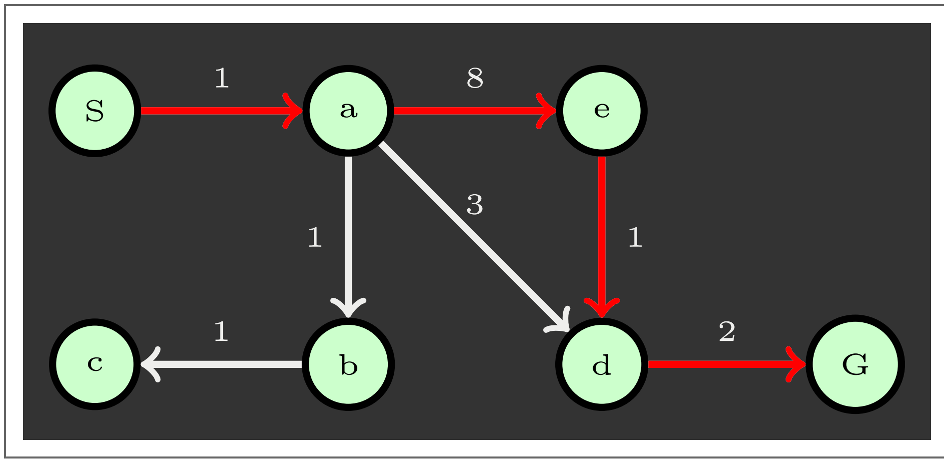
Greedy orders by goal proximity, or forward cost $h(n)$.

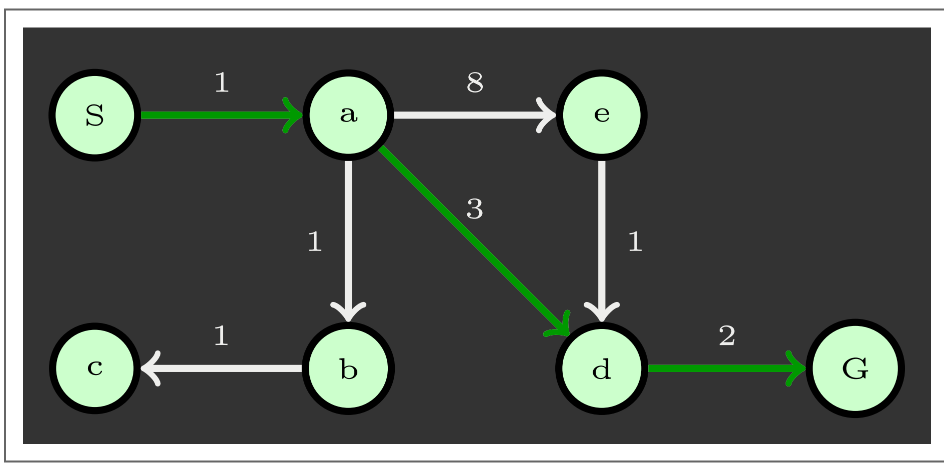
A^* Search orders by the sum: $f(n) = g(n) + h(n)$



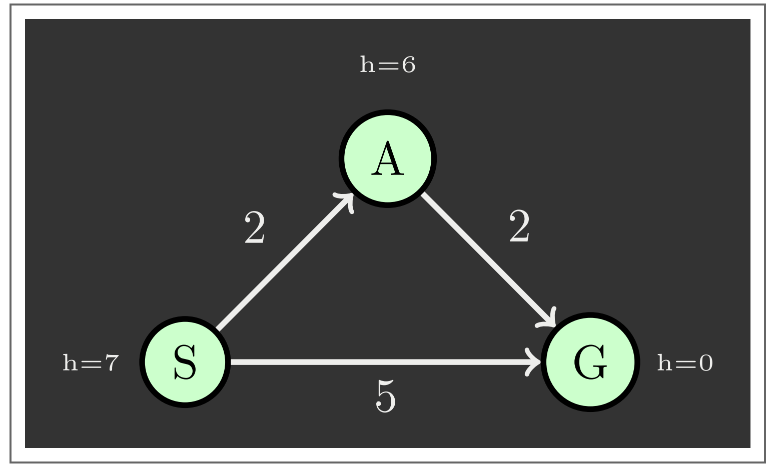








IS A^* OPTIMAL?



What went wrong?

Actual goal cost $\leq$ estimated goal cost

We need estimates to be less than actual costs

ADMISSIBILITY

Inadmissible (pessimistic) heuristics break optimality by trapping good plans on the fringe.

Admissible (optimistic) heuristics slow down bad plans but never outweigh true costs

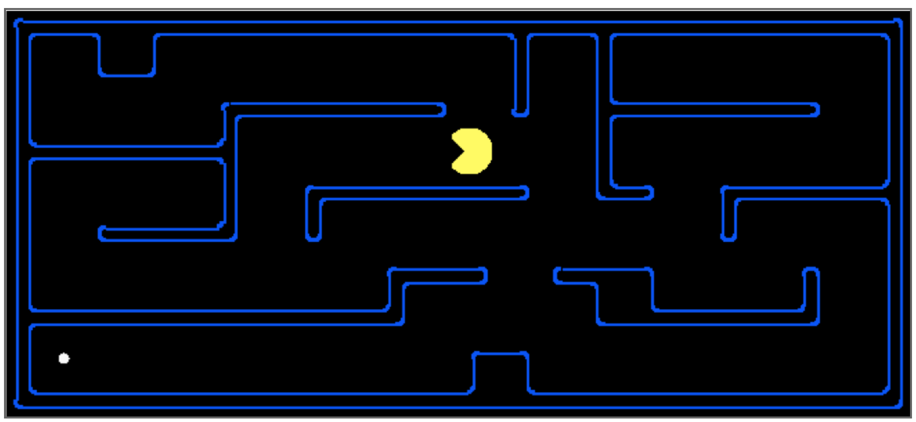
ADMISSIBLE HEURISTICS

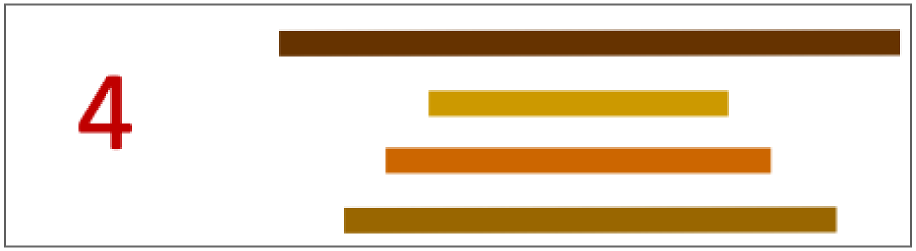
A heuristic h is admissible (optimistic) if:

$$0 \leq h(n) \leq h^*(n)$$

where $h^*(n)$ is the true cost to a nearest goal

Example:





In practice, coming up with an admissible heuristic is most of what is involved in using A^*.

OPTIMALITY OF A^* TREE SEARCH

Assume:

- A is an optimal goal node
- B is a suboptimal goal node
- h is admissible

Claim:

- A will exit the fringe before B

OPTIMALITY OF A^* TREE SEARCH

Proof:

Imagine B is on the fringe

Some ancestor n of A is on the fringe too

Claim: n will be expanded before B

- $f(n)$ is less or equal to $f(A)$
- $f(A)$ is less than $f(B)$
- n expands before B

All ancestors of A expand before B

A expands before B

A^* search is optimal

$$f(n) = g(n) + h(n)$$

$$f(n) \leq g(A) \;\; \textbf{admissibility o}$$

$$g(A) = f(A) \;\; h = 0 \;\; \textbf{at goal}$$

$$g(A) \leq g(B) \;\; B \textbf{ is suboptim}$$

$$f(A) \leq f(B) \;\; h = 0 \textbf{ at goal}$$

$$f(n) \leq f(A) < f(B)$$

UCS VS A^* CONTOURS

Uniform-cost expands equally in all ”directions”

A^* expands mainly toward the goal, but does hedge its bets to ensure optimality

A^* DEMO

A^* APPLICATIONS

Video games

Pathing / routing problems

Resource planning problems

Robot motion planning

Language analysis

Machine translation

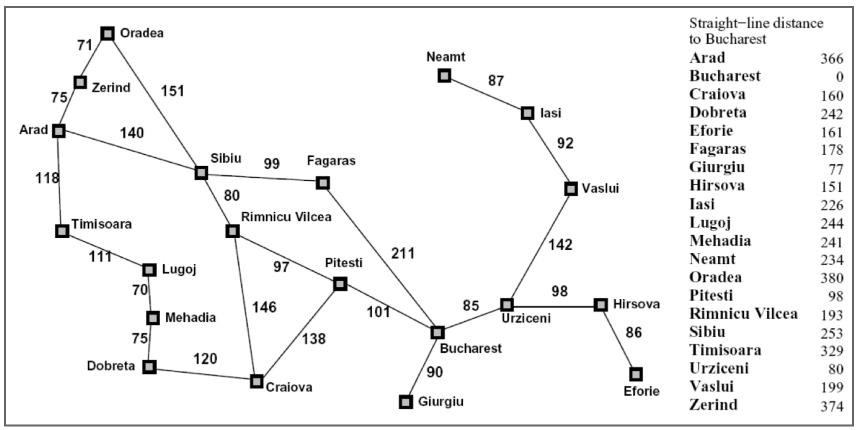
Speech recognition

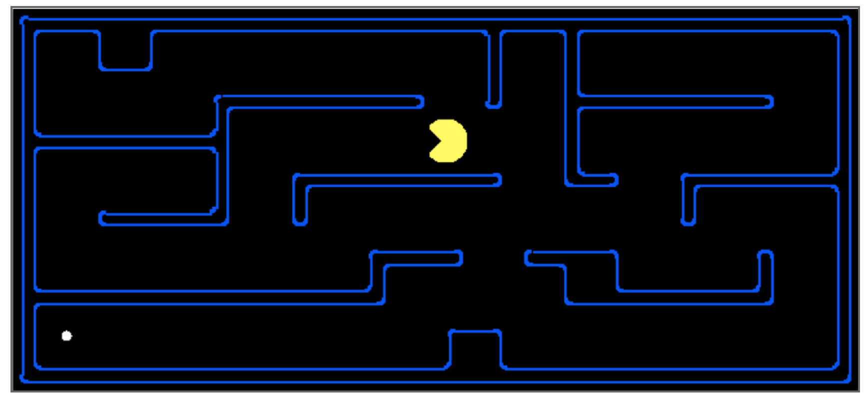
...

CREATING ADMISSIBLE HEURISTICS

Most of the work in solving hard search problems optimally is in coming up with admissible heuristics

Often, admissible heuristics are solutions to relaxed problems, where new actions are available





Inadmissible heuristics can often be useful too.

A^* SUMMARY

A^* uses both backward costs and (estimates of) forward costs

A^* is optimal with admissible heuristics

Heuristic design is key: often use relaxed problems

DESIGNING HEURISTIC AS A SEARCH PROBLEM

Article | Open access | Published: 14 December 2023

Mathematical discoveries from program search with large language models

Bernardino Romera-Paredes, Mohammadamin Barekatain, Alexander Novikov, Matej Balog, M. Pawan Kumar, Emilien Dupont, Francisco J. R. Ruiz, Jordan S. Ellenberg, Pengming Wang, Omar Fawzi, Pushmeet Kohli & Alhussein Fawzi

Nature **625**, 468–475 (2024) | Cite this article

Abstract

Large language models (LLMs) have demonstrated tremendous capabilities in solving complex tasks, from quantitative reasoning to understanding natural language. However, LLMs sometimes suffer from confabulations (or hallucinations), which can result in them making plausible but incorrect statements[1,2]. This hinders the use of current large models in scientific discovery. Here we introduce FunSearch (short for searching in the function space), an evolutionary procedure based on pairing a pretrained LLM with a systematic evaluator. We demonstrate the effectiveness of this approach to surpass the best-known results in important problems, pushing the boundary of existing LLM-based approaches[3]. Applying FunSearch to a central problem in extremal combinatorics—the cap set problem—we discover new constructions of large cap sets going beyond the best-known ones, both in finite dimensional and asymptotic cases. This shows that it is possible to make discoveries for established open problems using LLMs. We showcase the generality of FunSearch by applying

Associated content

Large language models help computer programs to evolve

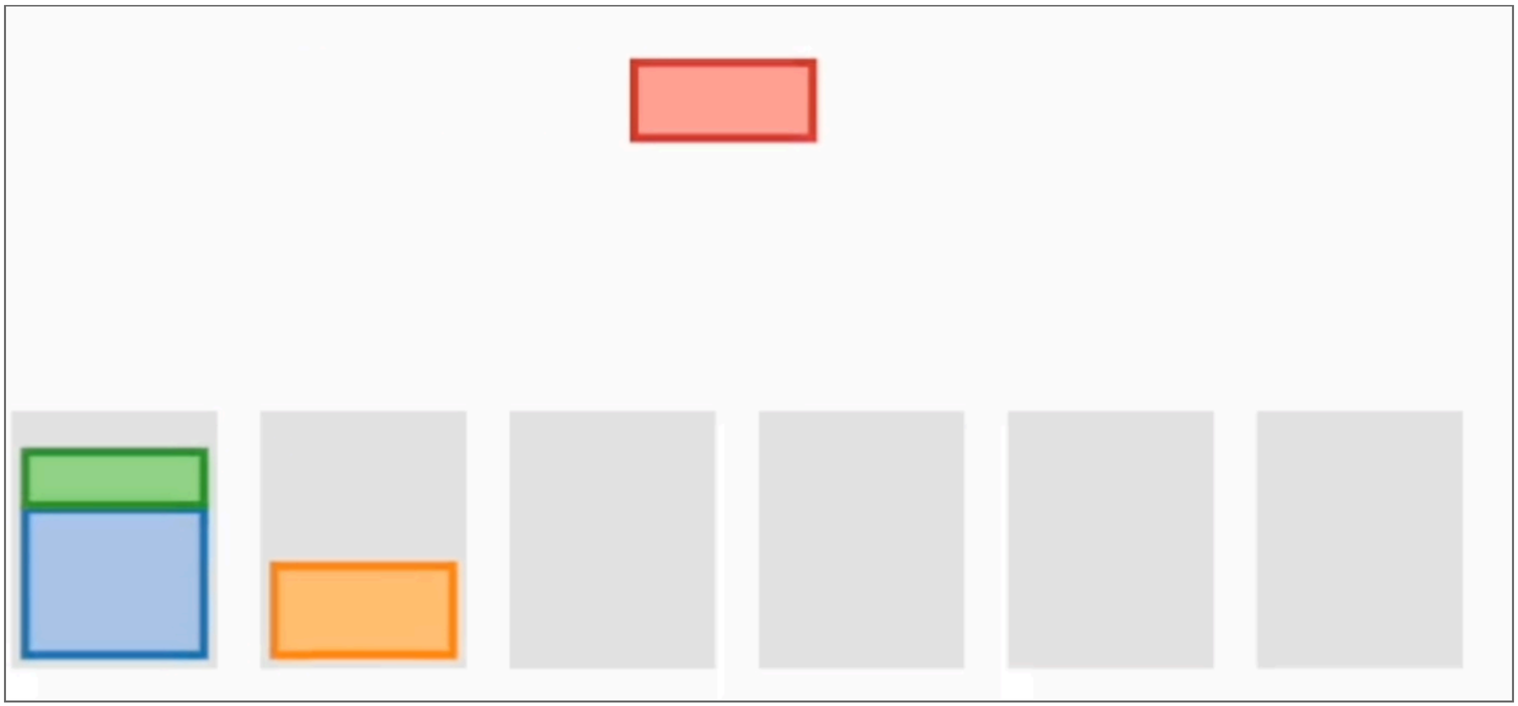
Jean-Baptiste Mouret

Nature | **News & Views** | 17 Jan 2024

Sections | Figures | References

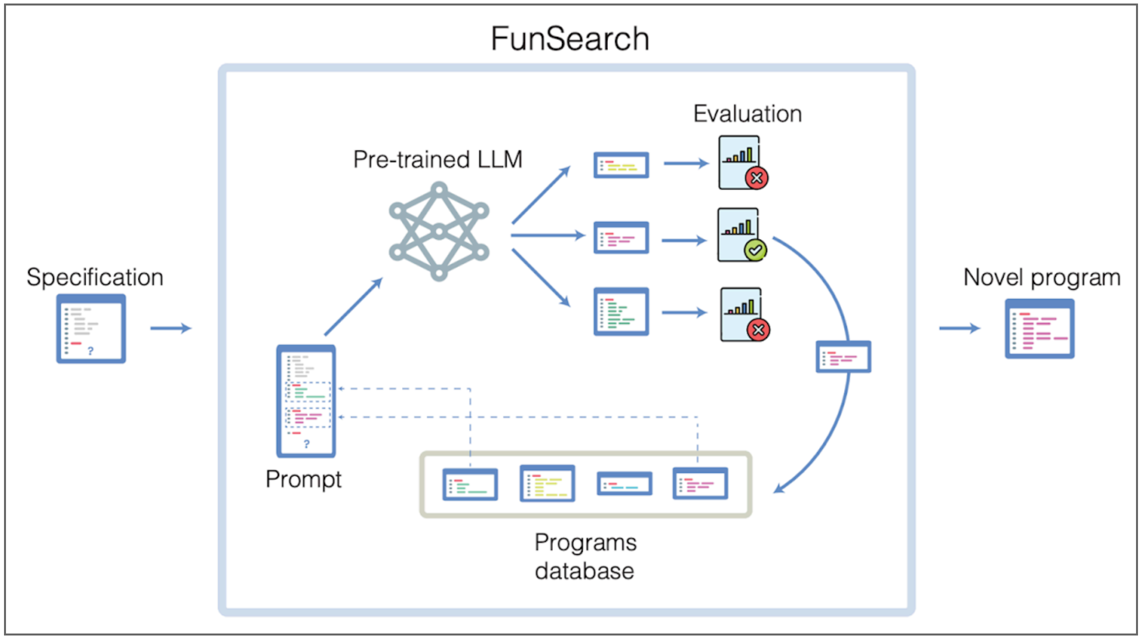
DESIGNING HEURISTIC AS A SEARCH PROBLEM

ONLINE BIN PACKING



DESIGNING HEURISTIC AS A SEARCH PROBLEM

ONLINE BIN PACKING



DESIGNING HEURISTIC AS A SEARCH PROBLEM

ONLINE BIN PACKING

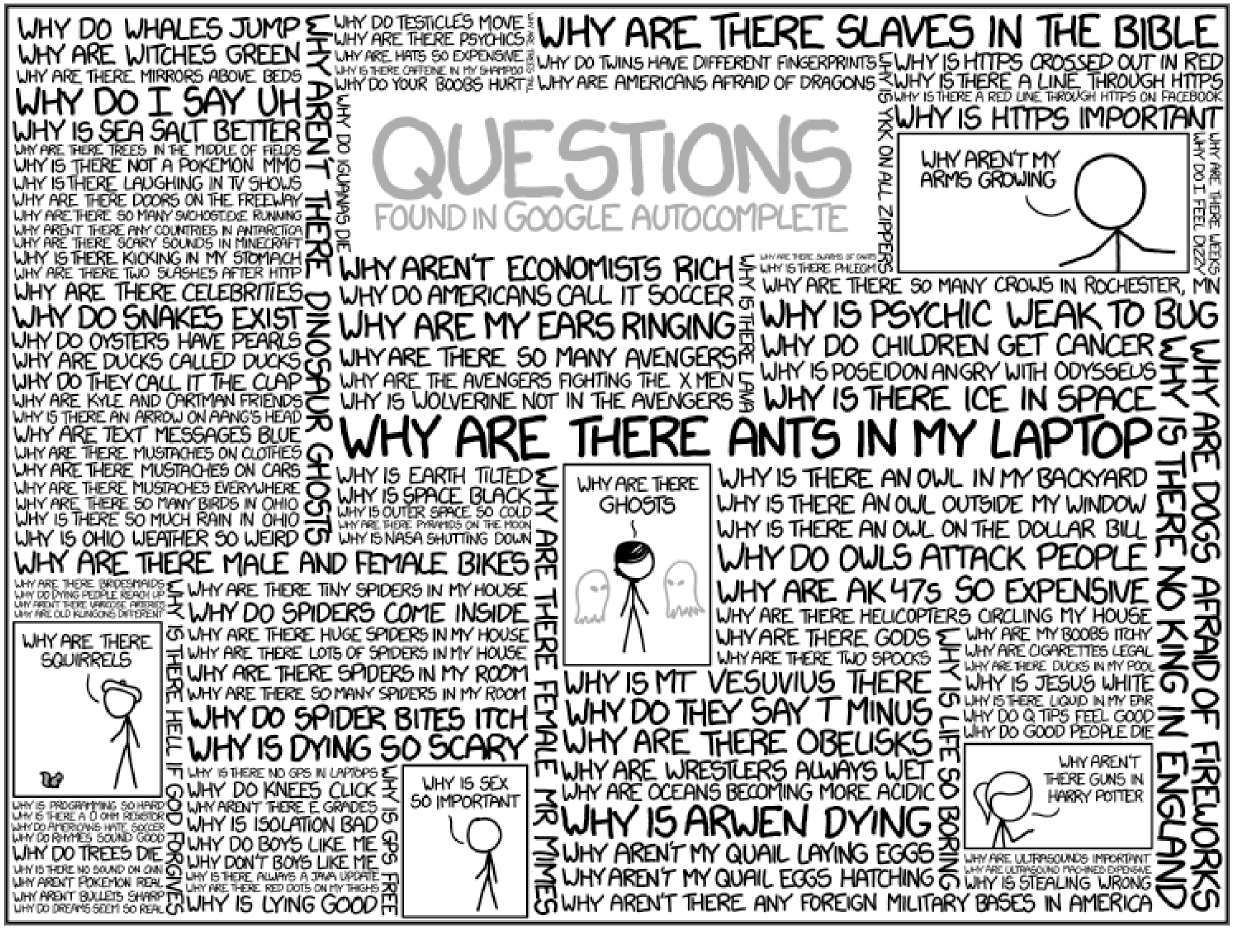
```python
def best_fit_heuristic(item: float, bins: np.ndarray) -> np.ndarray:
  """Returns priority with which we want to add item to each bin.

  Args:
    item: Size of item to be added to the bin.
    bins: Array of capacities for each bin.

  Return:
    Array of same size as bins with priority score of each bin.
  """
  return np.argmin(bins - item)
```

```python
def FunSearch_heuristic(item: float, bins: np.ndarray) -> np.ndarray:
  """Heuristic discovered for the Weibull datasets."""
  max_bin_cap = max(bins)
  score = (bins - max_bin_cap)**2 / item + bins**2 / (item**2)
  score += bins**2 / item**3
  score[bins > item] = -score[bins > item]
  score[1:] -= score[:-1]
  return np.argmax(score)
```

DESIGNING HEURISTIC AS A SEARCH PROBLEM

ONLINE BIN PACKING

Q & A


QUESTIONS
FOUND IN GOOGLE AUTOCOMPLETE
WHY DO WHALES JUMP
WHY ARE WITCHES GREEN
WHY ARE THERE MIRRORS ABOVE BEDS
WHY DO I SAY UH
WHY IS SEA SALT BETTER
WHY ARE THERE TREES IN THE MIDDLE OF FIELDS
WHY IS THERE NOT A POKEMON MMO
WHY IS THERE LAUGHING IN TV SHOWS
WHY ARE THERE DOORS ON THE FREEWAY
WHY ARE THERE SO MANY SVCHOST.EXE RUNNING
WHY AREN'T THERE ANY COUNTRIES IN ANTARCTICA
WHY ARE THERE SCARY SOUNDS IN MINECRAFT
WHY IS THERE KICKING IN MY STOMACH
WHY ARE THERE TWO SLASHES AFTER HTTP
WHY ARE THERE CELEBRITIES
WHY DO SNAKES EXIST
WHY DO OYSTERS HAVE PEARLS
WHY ARE DUCKS CALLED DUCKS
WHY DO THEY CALL IT THE CLAP
WHY ARE KYLE AND CARTMAN FRIENDS
WHY IS THERE AN ARROW ON AANG'S HEAD
WHY ARE TEXT MESSAGES BLUE
WHY ARE THERE MUSTACHES ON CLOTHES
WHY ARE THERE MUSTACHES ON CARS
WHY ARE THERE MUSTACHES EVERYWHERE
WHY ARE THERE SO MANY BIRDS IN OHIO
WHY IS THERE SO MUCH RAIN IN OHIO
WHY IS OHIO WEATHER SO WEIRD
WHY AREN'T THERE DINOSAUR GHOSTS
WHY DO IGUANAS DIE
WHY DO TESTICLES MOVE
WHY ARE THERE PSYCHICS
WHY ARE HATS SO EXPENSIVE
WHY IS THERE CAFFEINE IN MY SHAMPOO
WHY DO YOUR BOOBS HURT
WHY ARE THERE SLAVES IN THE BIBLE
WHY DO TWINS HAVE DIFFERENT FINGERPRINTS
WHY ARE AMERICANS AFRAID OF DRAGONS
WHY IS YKK ON ALL ZIPPERS
WHY IS HTTPS CROSSED OUT IN RED
WHY IS THERE A LINE THROUGH HTTPS
WHY IS THERE A RED LINE THROUGH HTTPS ON FACEBOOK
WHY IS HTTPS IMPORTANT
WHY AREN'T MY ARMS GROWING
WHY ARE THERE WEEKS
WHY DO I FEEL DIZZY
WHY AREN'T ECONOMISTS RICH
WHY DO AMERICANS CALL IT SOCCER
WHY ARE MY EARS RINGING
WHY ARE THERE SO MANY AVENGERS
WHY ARE THE AVENGERS FIGHTING THE X MEN
WHY IS WOLVERINE NOT IN THE AVENGERS
WHY IS THERE LAVA
WHY IS THERE PHLEGM
WHY ARE THERE SO MANY CROWS IN ROCHESTER, MN
WHY IS PSYCHIC WEAK TO BUG
WHY DO CHILDREN GET CANCER
WHY IS POSEIDON ANGRY WITH ODYSSEUS
WHY IS THERE ICE IN SPACE
WHY ARE THERE ANTS IN MY LAPTOP
WHY IS EARTH TILTED
WHY IS SPACE BLACK
WHY IS OUTER SPACE SO COLD
WHY ARE THERE PYRAMIDS ON THE MOON
WHY IS NASA SHUTTING DOWN
WHY ARE THERE GHOSTS
WHY IS THERE AN OWL IN MY BACKYARD
WHY IS THERE AN OWL OUTSIDE MY WINDOW
WHY IS THERE AN OWL ON THE DOLLAR BILL
WHY DO OWLS ATTACK PEOPLE
WHY ARE AK47s SO EXPENSIVE
WHY ARE THERE HELICOPTERS CIRCLING MY HOUSE
WHY ARE THERE GODS
WHY ARE THERE TWO SPOCKS
WHY ARE THERE MALE AND FEMALE BIKES
WHY ARE THERE BRIDESMAIDS
WHY DO DYING PEOPLE REACH UP
WHY AREN'T THERE VARICOSE ARTERIES
WHY ARE OLD KLINGONS DIFFERENT
WHY ARE THERE SQUIRRELS
WHY ARE THERE TINY SPIDERS IN MY HOUSE
WHY DO SPIDERS COME INSIDE
WHY ARE THERE HUGE SPIDERS IN MY HOUSE
WHY ARE THERE LOTS OF SPIDERS IN MY HOUSE
WHY ARE THERE SPIDERS IN MY ROOM
WHY ARE THERE SO MANY SPIDERS IN MY ROOM
WHY DO SPIDER BITES ITCH
WHY IS DYING SO SCARY
WHY IS THERE HELL IF GOD FORGIVES
WHY IS THERE NO GPS IN LAPTOPS
WHY DO KNEES CLICK
WHY AREN'T THERE E GRADES
WHY IS ISOLATION BAD
WHY DO BOYS LIKE ME
WHY DON'T BOYS LIKE ME
WHY IS THERE ALWAYS A JAVA UPDATE
WHY ARE THERE RED DOTS ON MY THIGHS
WHY IS LYING GOOD
WHY IS GPS FREE
WHY IS SEX SO IMPORTANT
WHY IS PROGRAMMING SO HARD
WHY IS THERE A 0 OHM RESISTOR
WHY DO AMERICANS HATE SOCCER
WHY DO RHYMES SOUND GOOD
WHY DO TREES DIE
WHY IS THERE NO SOUND ON CNN
WHY AREN'T POKEMON REAL
WHY AREN'T BULLETS SHARP
WHY DO DREAMS SEEM SO REAL
WHY ARE THERE FEMALE MR MIMES
WHY IS MT VESUVIUS THERE
WHY DO THEY SAY T MINUS
WHY ARE THERE OBELISKS
WHY ARE WRESTLERS ALWAYS WET
WHY ARE OCEANS BECOMING MORE ACIDIC
WHY IS ARWEN DYING
WHY AREN'T MY QUAIL LAYING EGGS
WHY AREN'T MY QUAIL EGGS HATCHING
WHY AREN'T THERE ANY FOREIGN MILITARY BASES IN AMERICA
WHY IS LIFE SO BORING
WHY ARE MY BOOBS ITCHY
WHY ARE CIGARETTES LEGAL
WHY ARE THERE DUCKS IN MY POOL
WHY IS JESUS WHITE
WHY IS THERE LIQUID IN MY EAR
WHY DO Q TIPS FEEL GOOD
WHY DO GOOD PEOPLE DIE
WHY AREN'T THERE GUNS IN HARRY POTTER
WHY ARE ULTRASOUNDS IMPORTANT
WHY ARE ULTRASOUND MACHINES EXPENSIVE
WHY IS STEALING WRONG
WHY IS THERE NO KING IN ENGLAND
WHY ARE DOGS AFRAID OF FIREWORKS

XKCD

Speaker notes