Uninformed Search

CS5491: Artificial Intelligence
ZHICHAO LU

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

TODAY (PART 1)

Uninformed Search

- Search Trees
- Search Algorithm Properties
- Depth First Search
- Breadth First Search
- Uniform Cost Search

Reading

- Today's Lecture: RN Chapter 3.3-3.4

XKCD

STATE SPACE GRAPHS AND SEARCH TREES

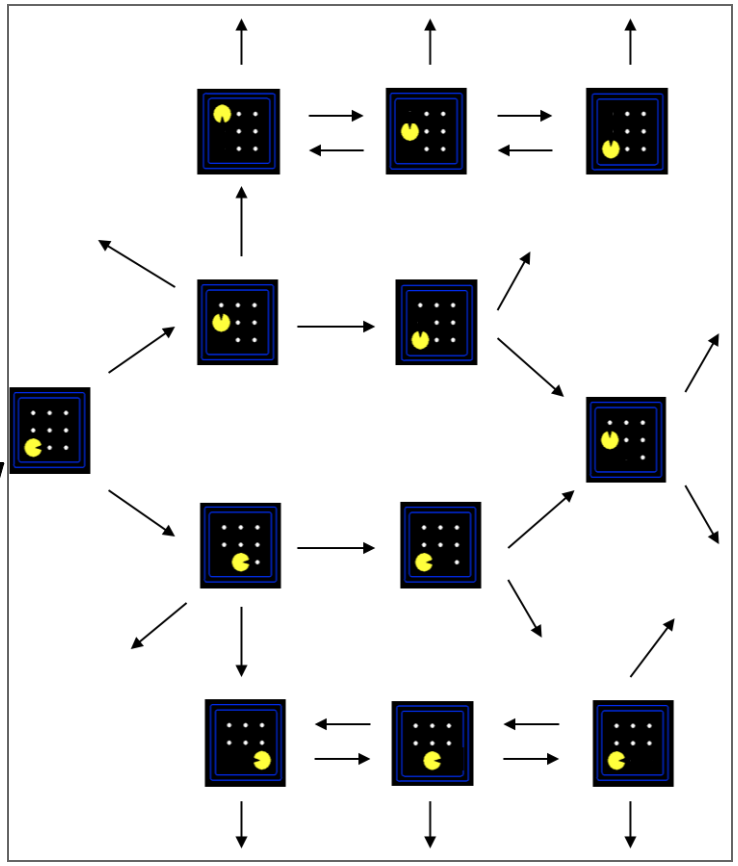
STATE SPACE GRAPHS

State Space Graph: A mathematical representation of a search problem

- Nodes are (abstracted) world configurations
- Arcs represent successors (action results)
- The goal test is a set of goal nodes (maybe only one)

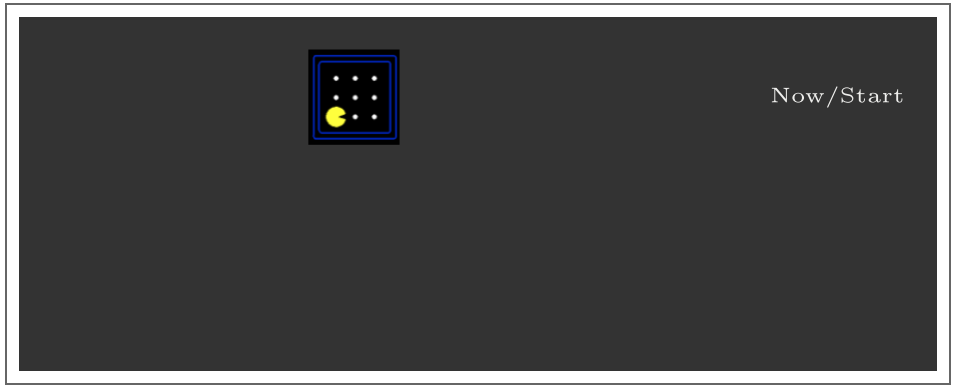
In a state space graph, each state occurs only once

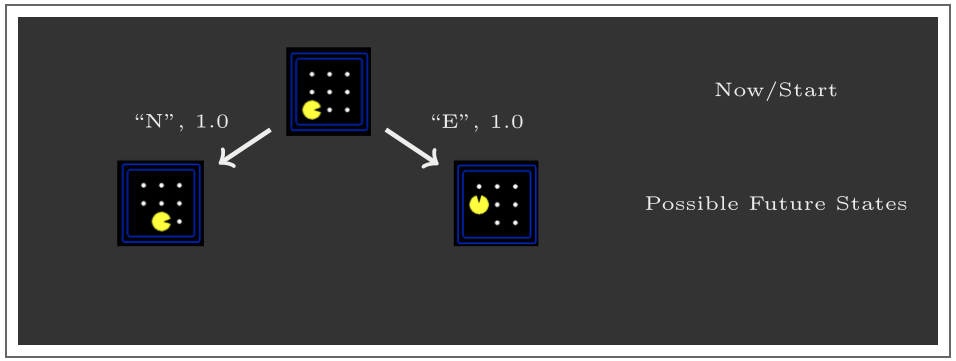
We can rarely build this full graph in memory (too big), but it is a useful idea

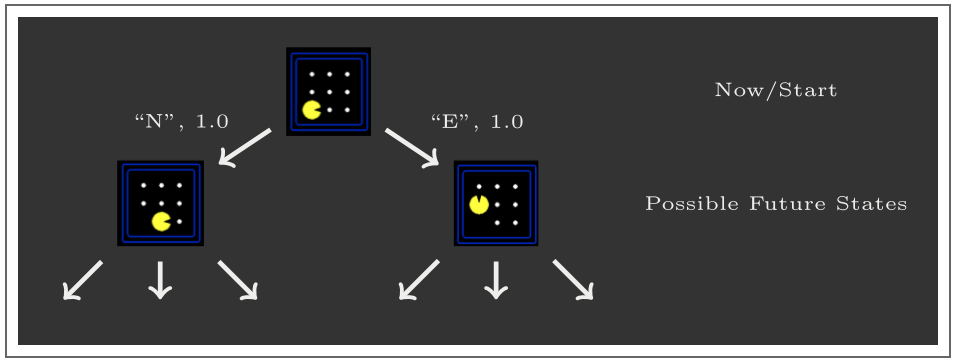


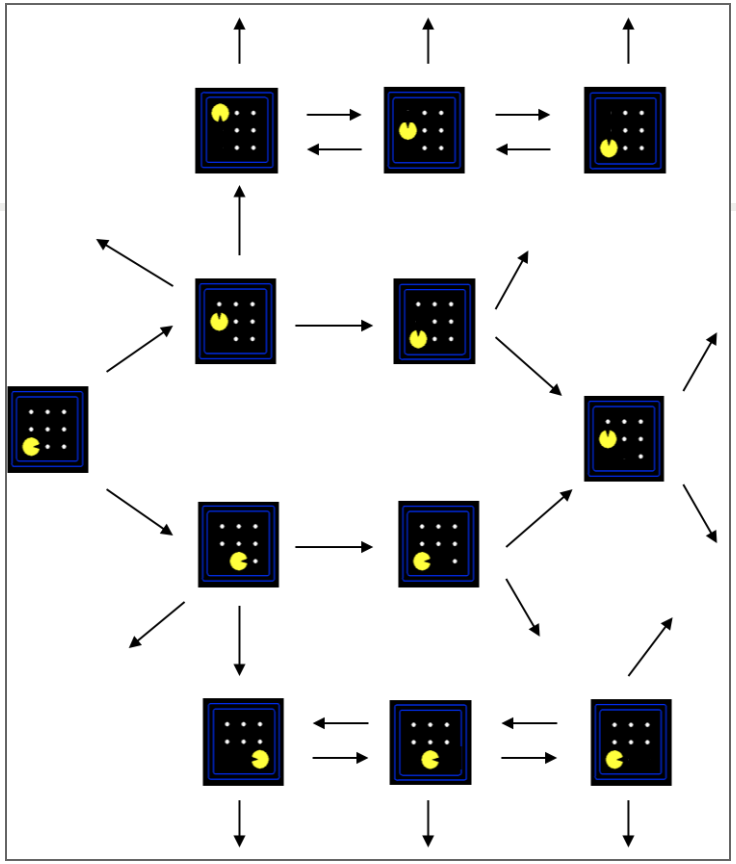
Tiny state space graph for a tiny search problem

SEARCH TREES



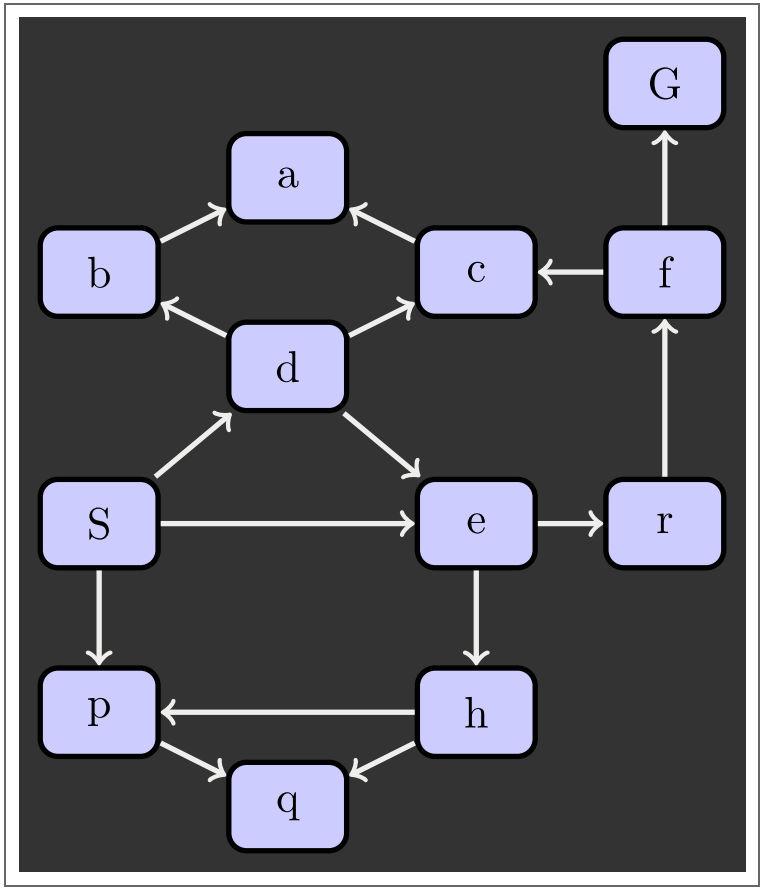






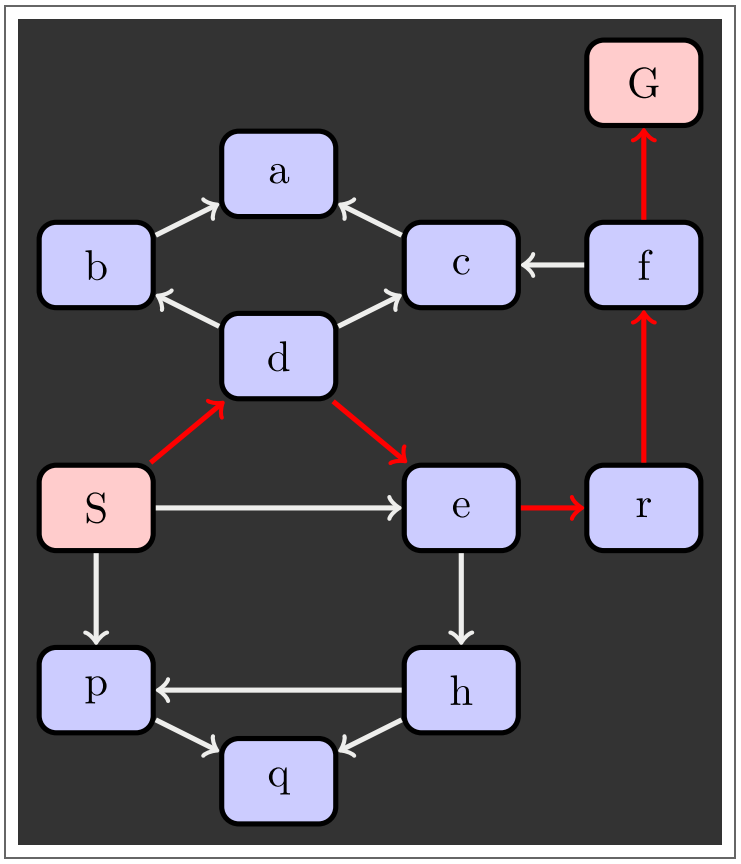
A search tree :

- A "what if" tree of plans and their outcomes
- The start state is the root node
- Child nodes correspond to successors
- Nodes show states, but correspond to plans/actions that achieve those states
- Building the whole tree is impossible for most problems

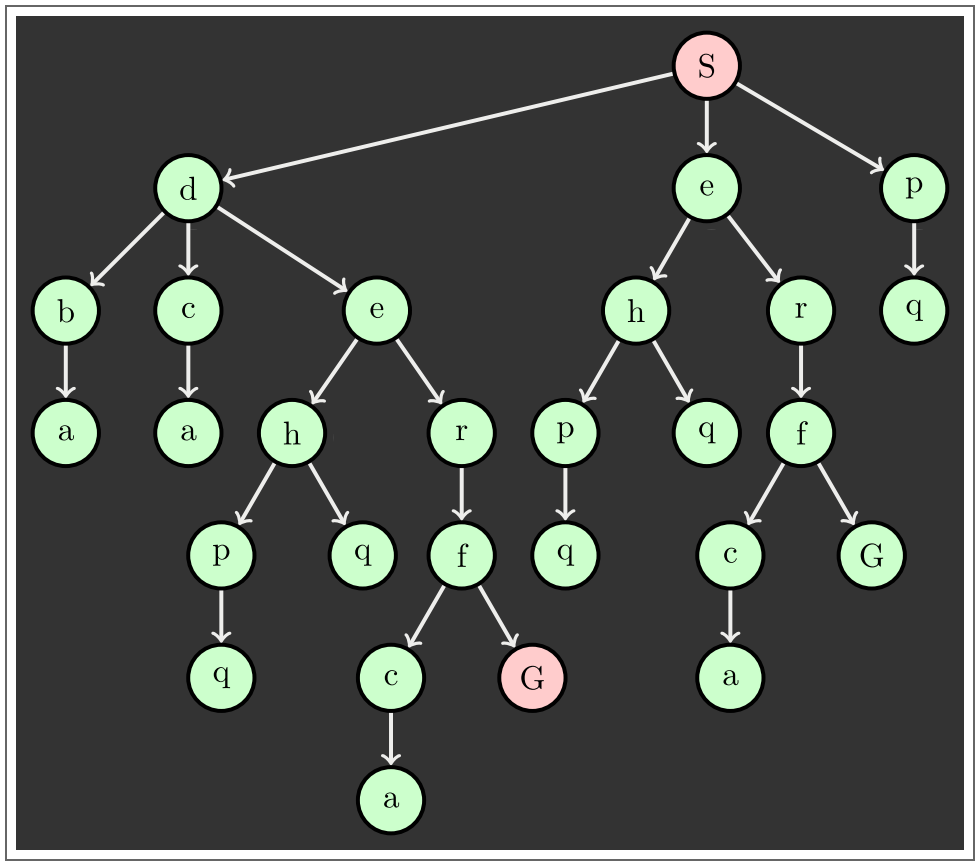


STATE SPACE VS SEARCH TREES

State Space Graph



Search Tree

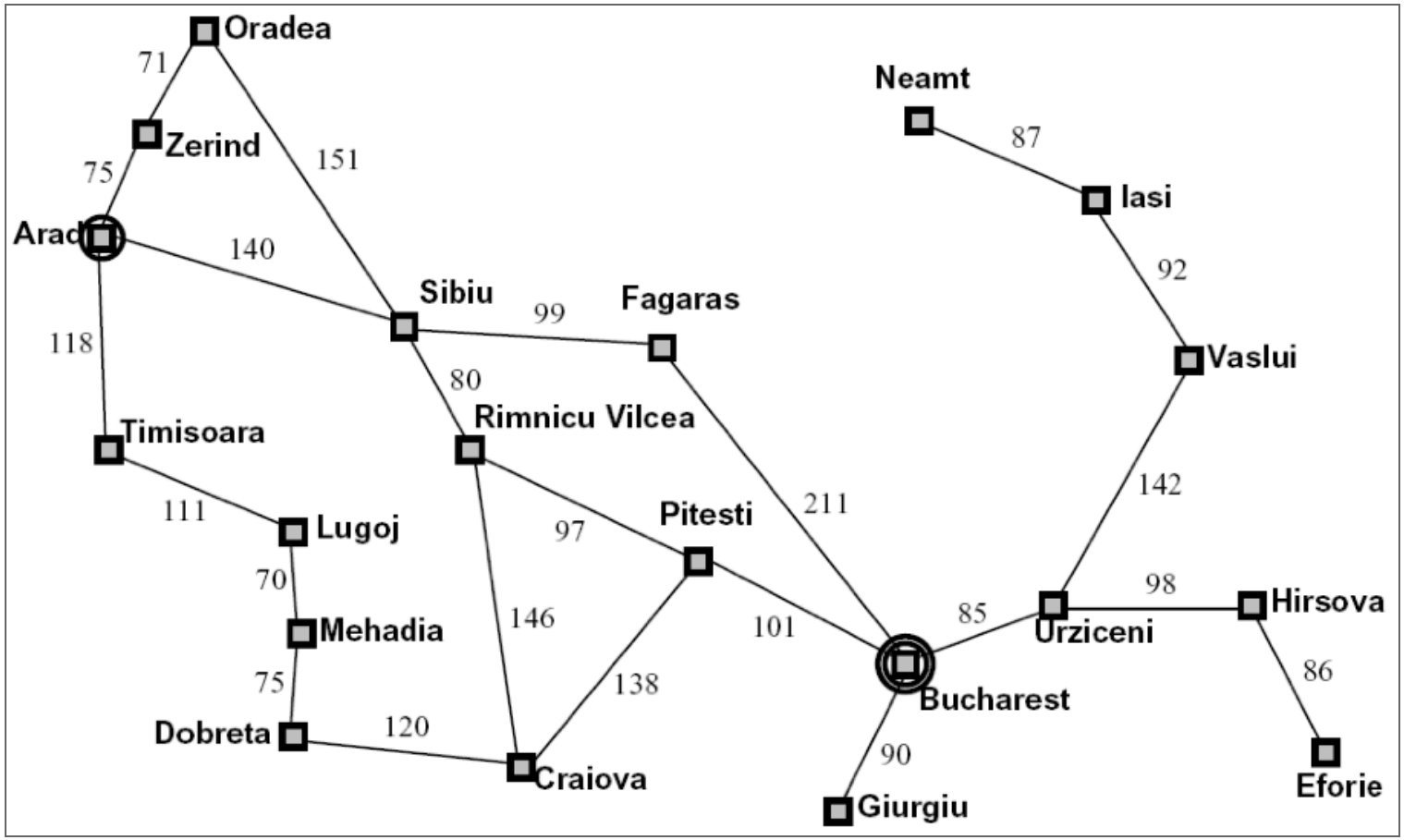


Each NODE in search tree is an entire PATH in state space graph.

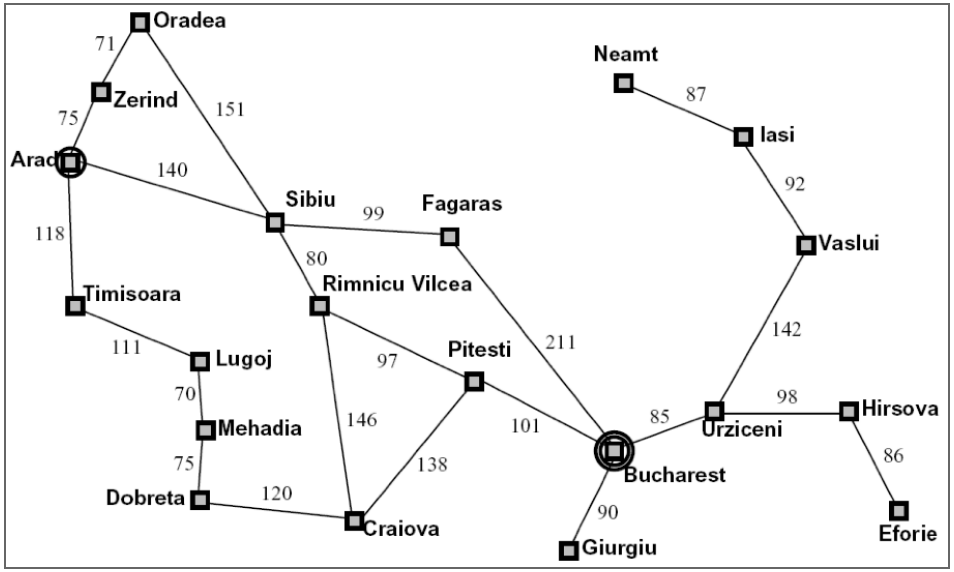
Construct both on demand – and construct as little as possible.

TREE SEARCH

SEARCH EXAMPLE: TRAVELING IN ROMANIA



SEARCH TREE: TRAVELING IN ROMANIA



Search:

- Expand out potential plans (tree nodes)
- Maintain a fringe of partial plans under consideration
- Try to expand as few tree nodes as possible

TREE SEARCH ALGORITHM

Tree Search

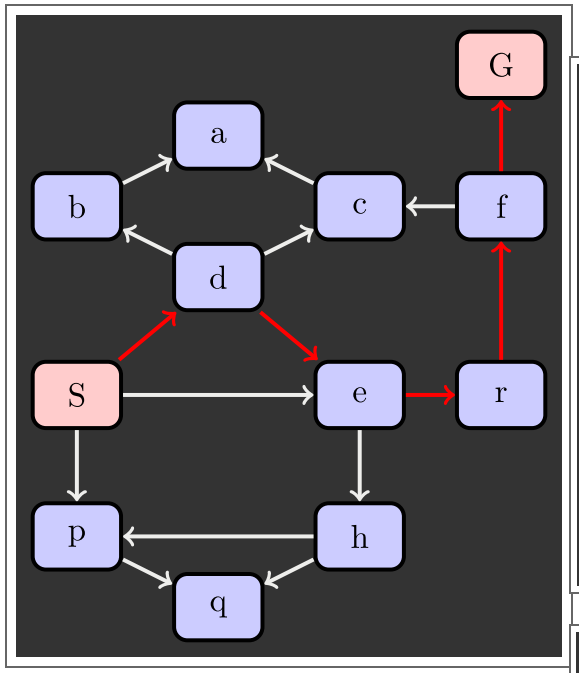
```
input  : problem, strategy
output: solution or failure
initialize the search tree using initial state of problem;
while forever do
    if there are no candidates for expansion then return failure;
    choose a leaf node for expansion according to strategy;
    if node contains a goal state then
        return the corresponding solution;
    else
        expand the node and add the resulting nodes to the
         search tree;
    end
end
```

Important Ideas:

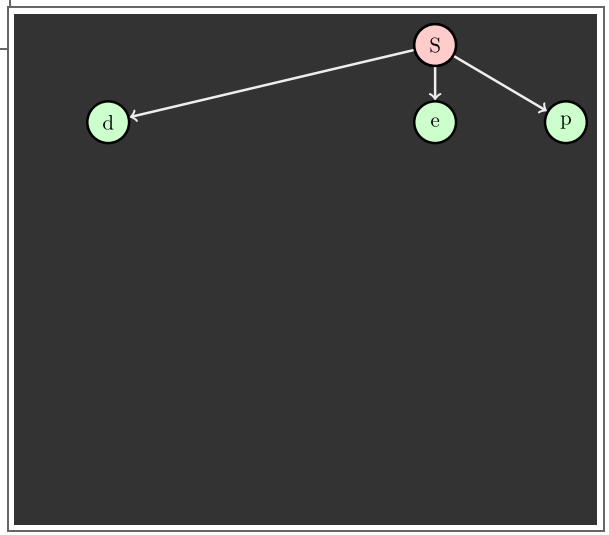
- Fringe
- Expansion
- Exploration Strategy

Main question: which fringe nodes to explore?

TREE SEARCH EXAMPLE



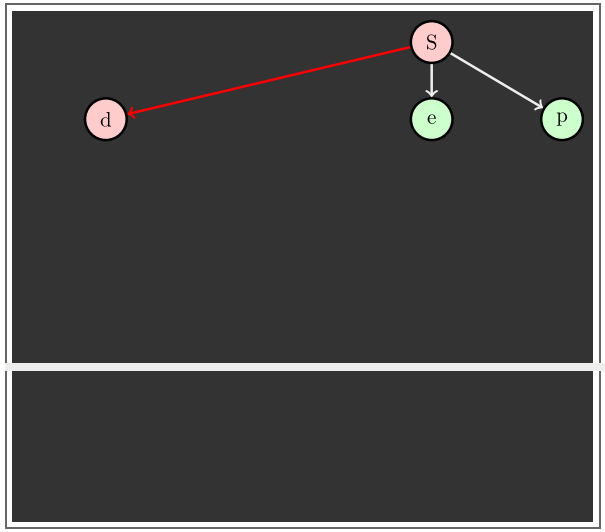
Search Tree



Search Tree Build

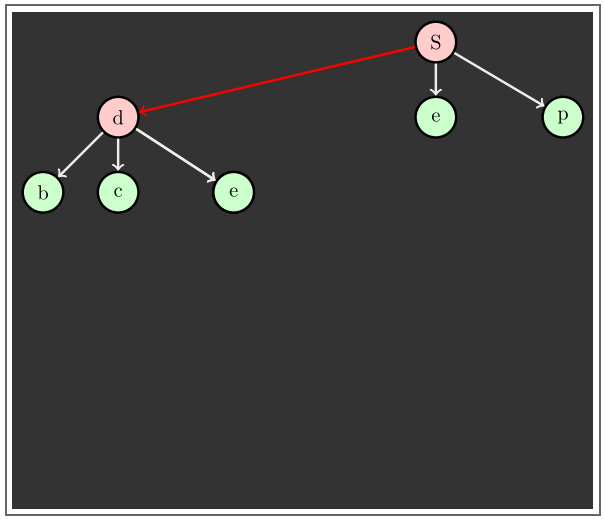
s

s
s → d
s → e
s → p

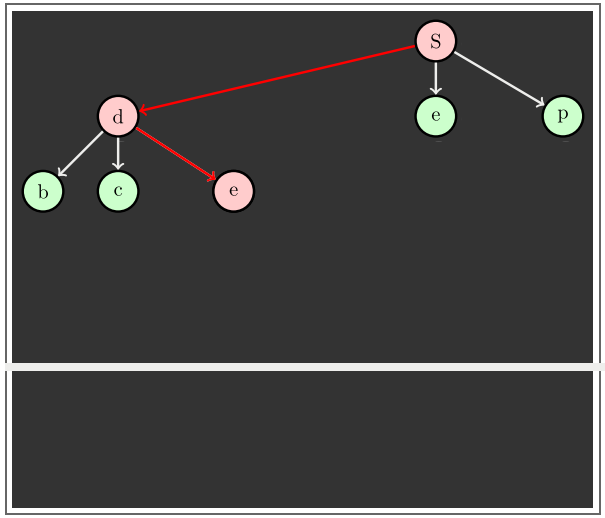


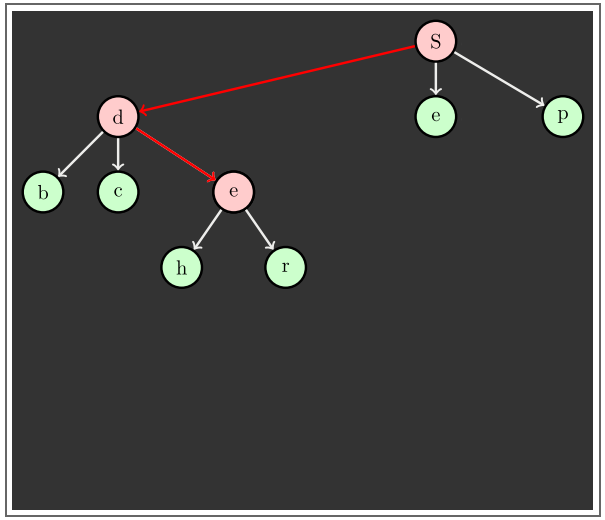
SEARCH ALGORITHM PROPERTIES

s (insert)
s → d
s → e
s → p



s (insert)
s → d
s → e
s → p
s → d → b
s → d → c
s → d → e





SEARCH ALGORITHM PROPERTIES

Complete: Guaranteed to find a solution if one exists?

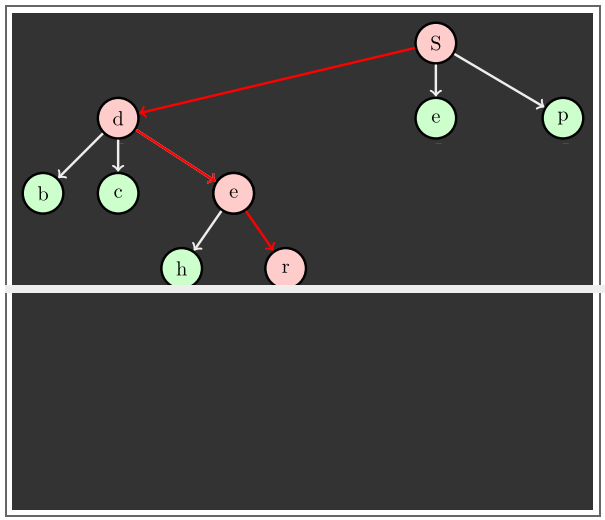
Optimal: Guaranteed to find the least cost path?

Time Complexity?

Space Complexity?

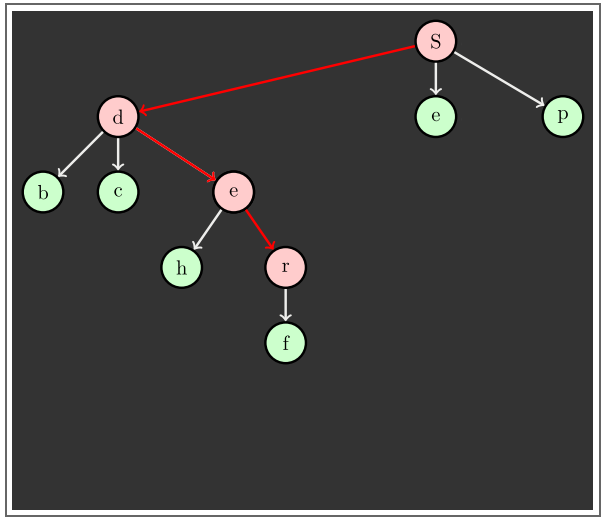
s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e

s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e
s → d → e → h
s → d → e → r

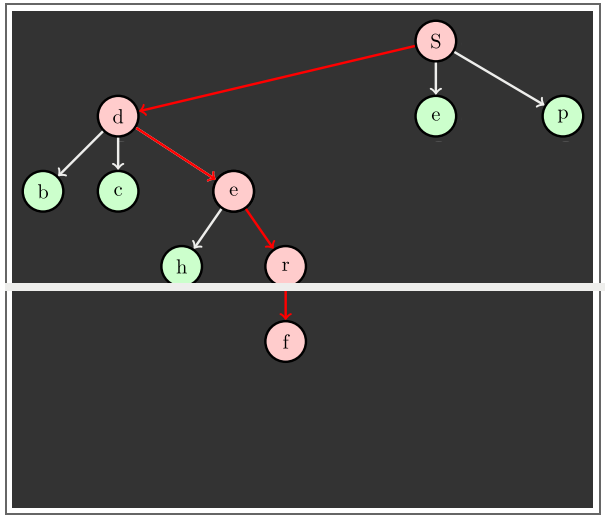


DEPTH-FIRST SEARCH

s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e (insert)
s → d → e → h
s → d → e → r

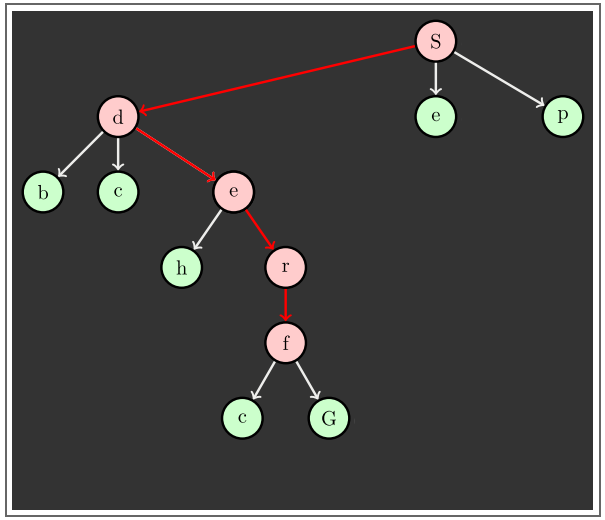


s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e (insert)
s → d → e → h
s → d → e → r
s → d → e → r → f

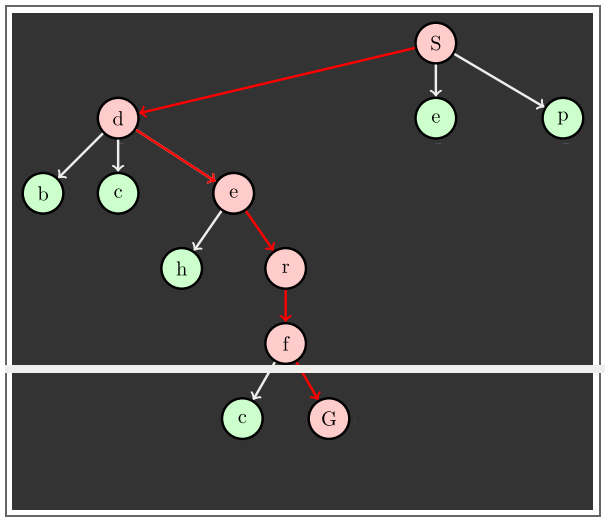


DEPTH FIRST SEARCH

s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e (insert)
s → d → e → h
s → d → e → r (insert)
s → d → e → r → f

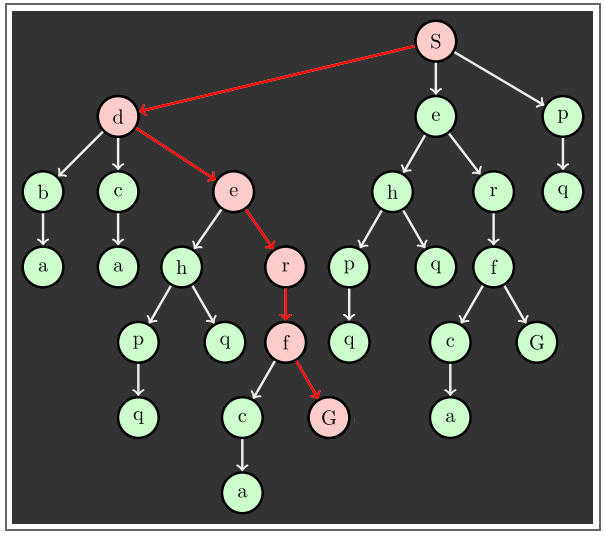


s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e (insert)
s → d → e → h
s → d → e → r (insert)
s → d → e → r → f
s → d → e → r → f → c
s → d → e → r → f → G



DEPTH-FIRST SEARCH (DFS) PROPERTIES

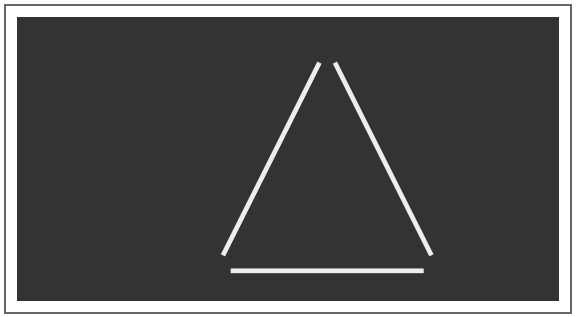
s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e (insert)
s → d → e → h
s → d → e → r (insert)
s → d → e → r → f (insert)
s → d → e → r → f → c
s → d → e → r → f → G



s (insert)
s → d (insert)
s → e
s → p
s → d → b
s → d → c
s → d → e (insert)
s → d → e → h
s → d → e → r (insert)
s → d → e → r → f (insert)
s → d → e → r → f → c
s → d → e → r → f → G (insert)

Cartoon of search tree:

- b is the branching factor
- m is the maximum depth

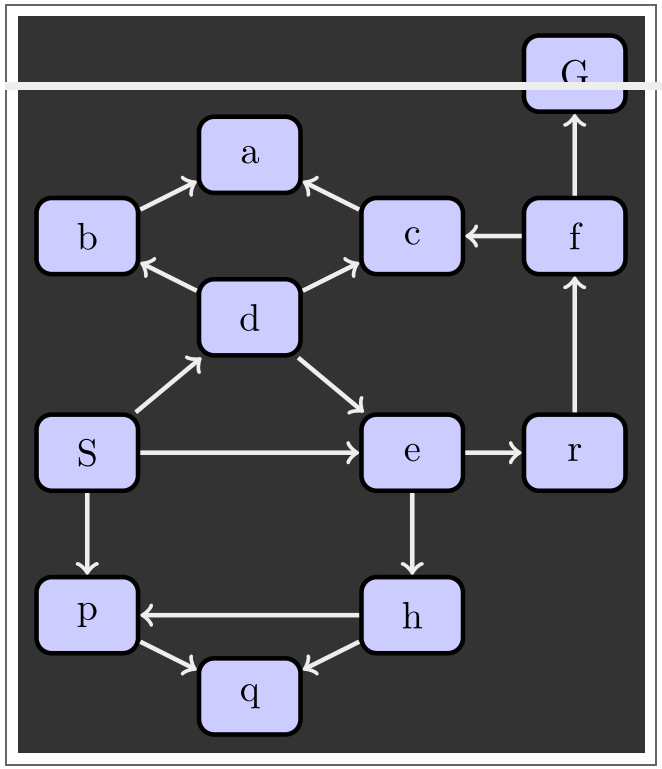


- solutions at various depths

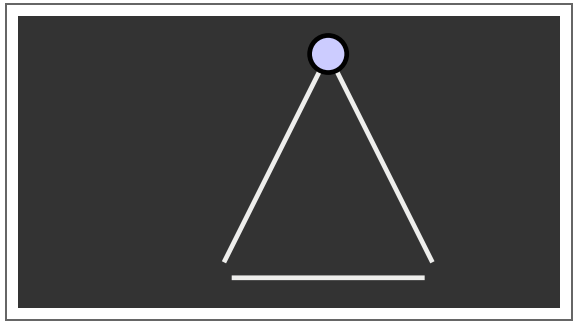
Number of nodes in a tree?

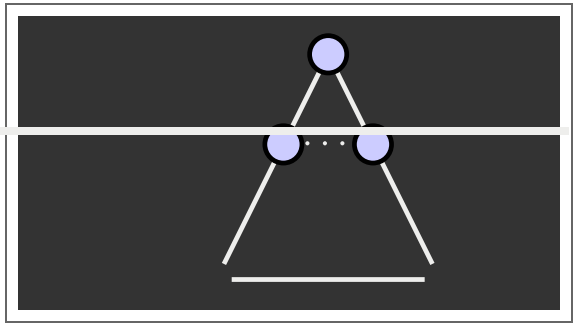
- $1 + b + b^2 + \cdots + b^m = \mathcal{O}(b^m)$

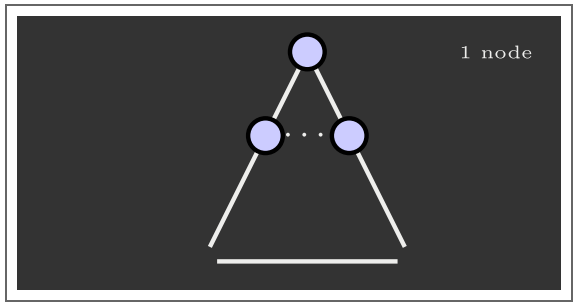
State Space Graph

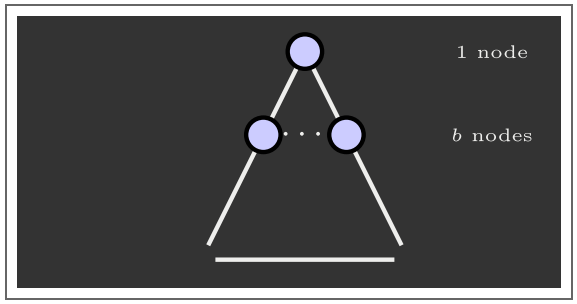


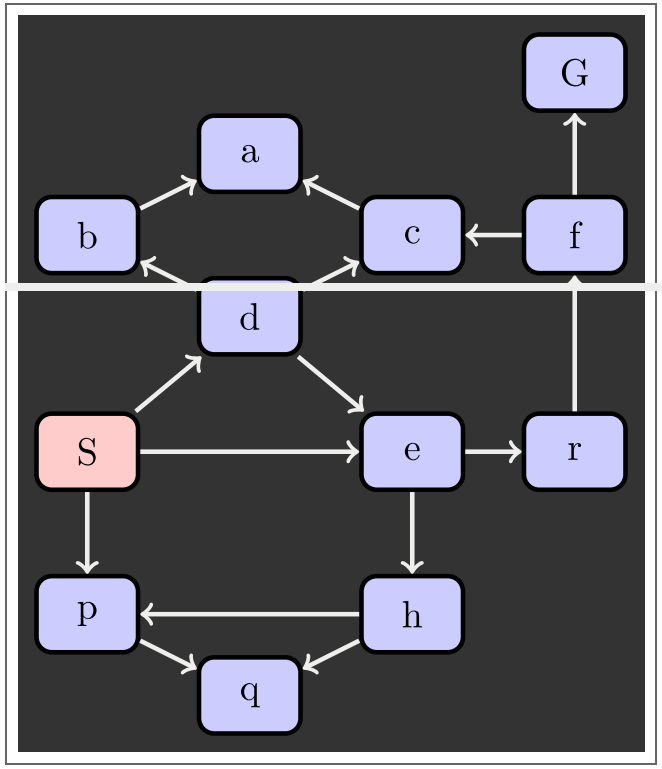
BREADTH-FIRST SEARCH



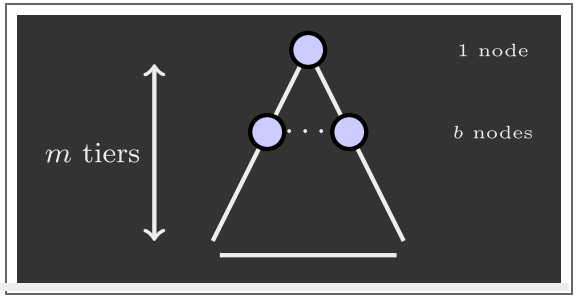


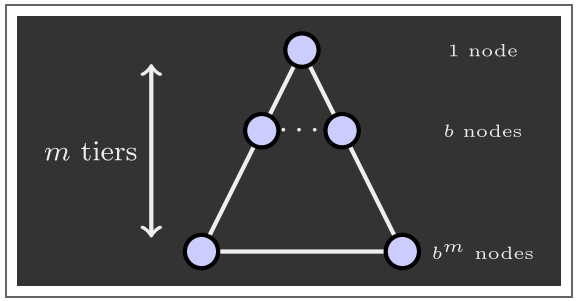


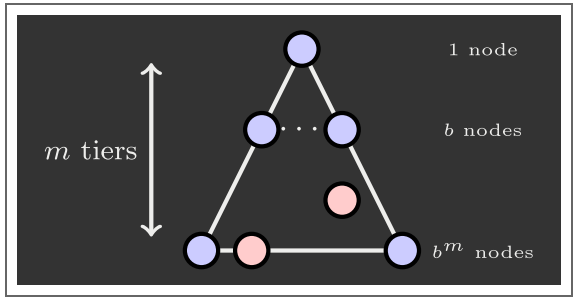




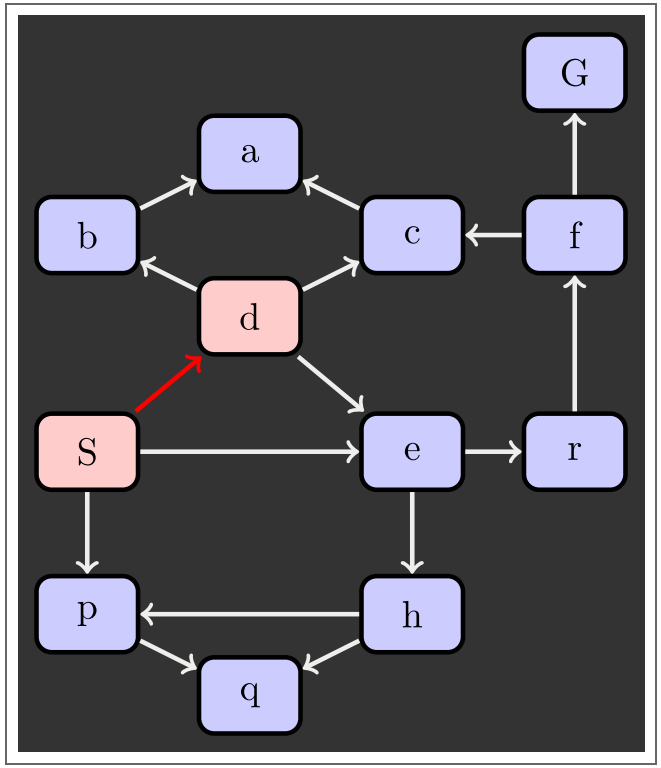
BREADTH FIRST SEARCH







Search Tree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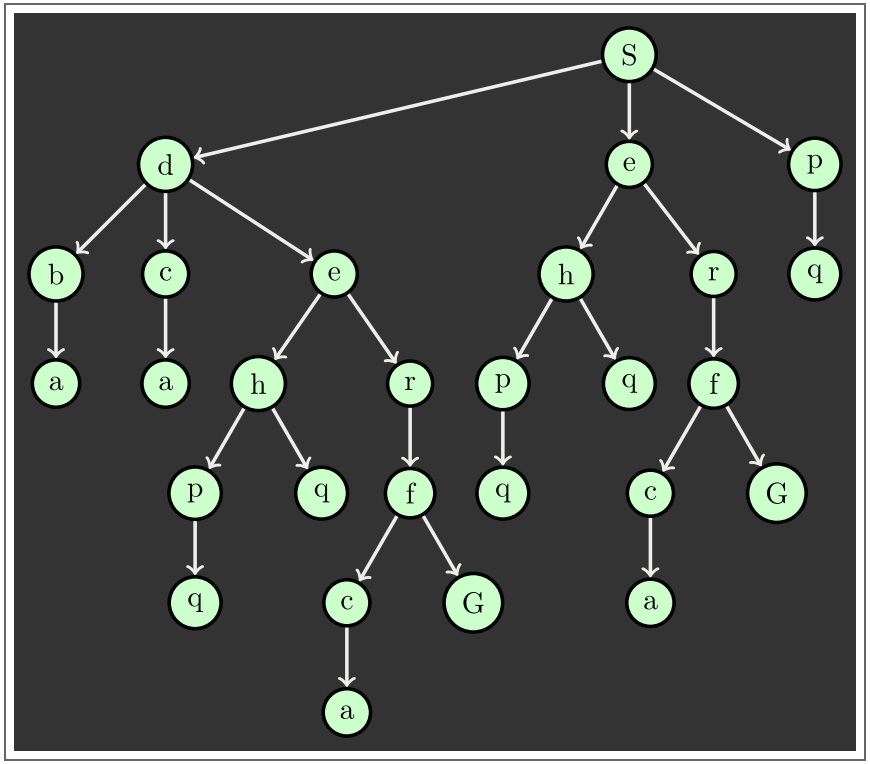
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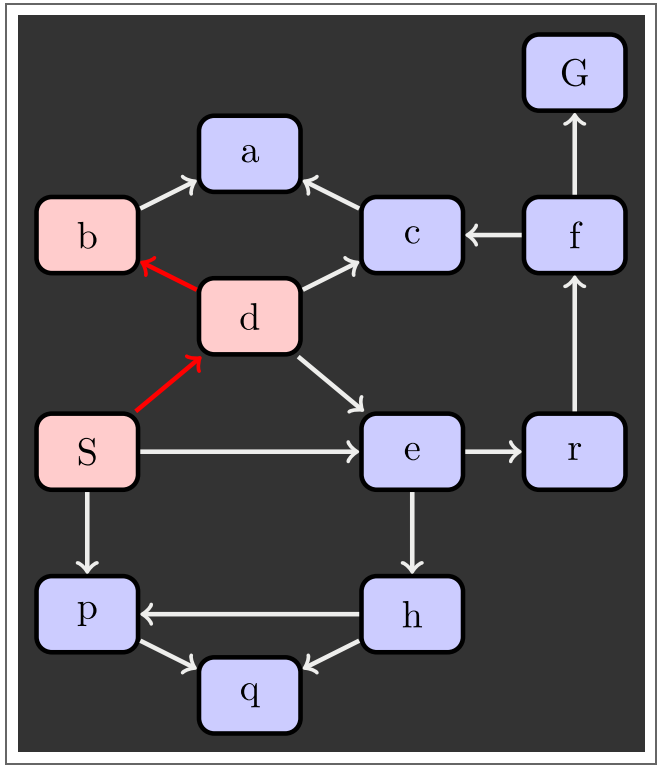
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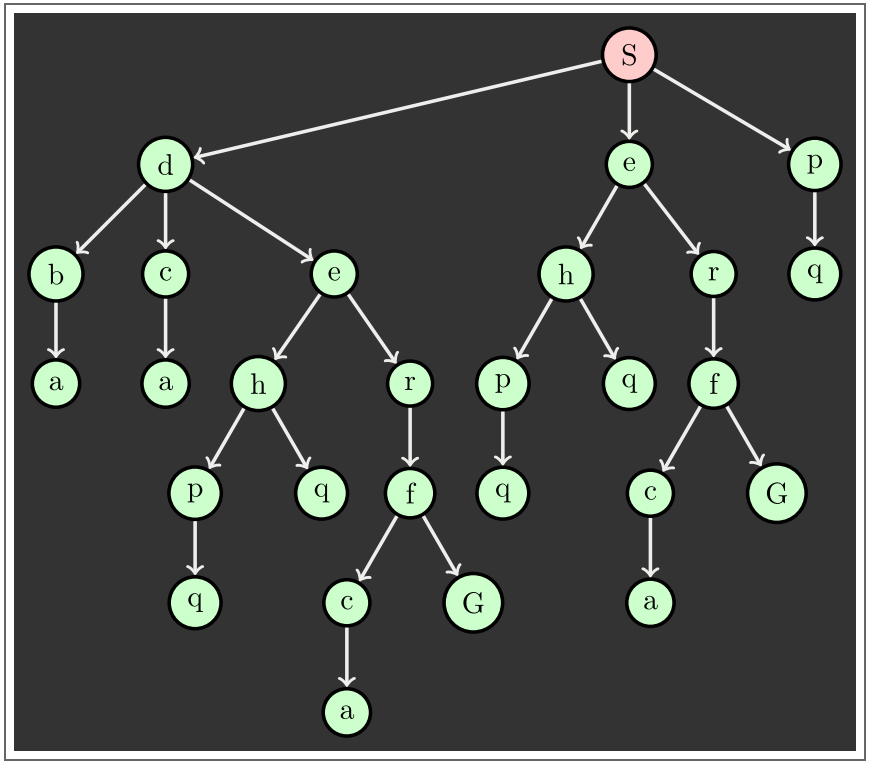
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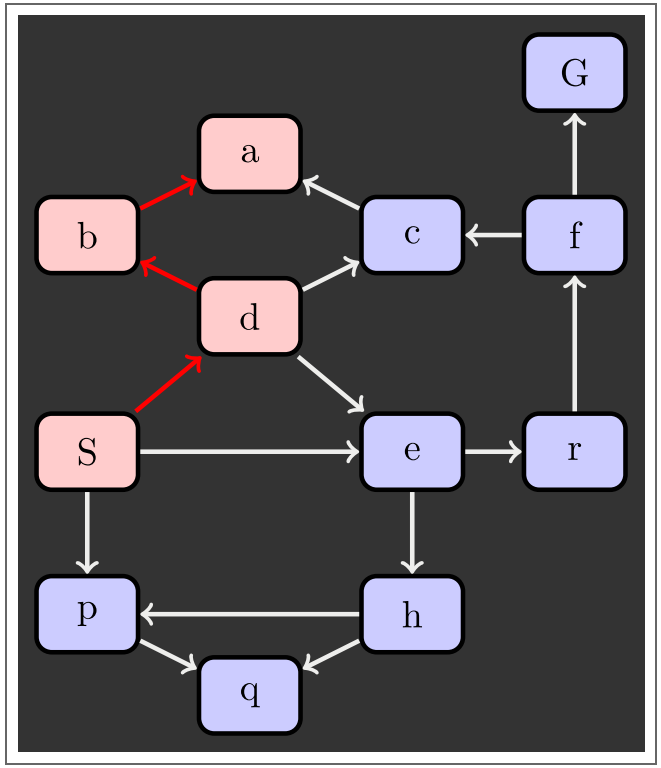
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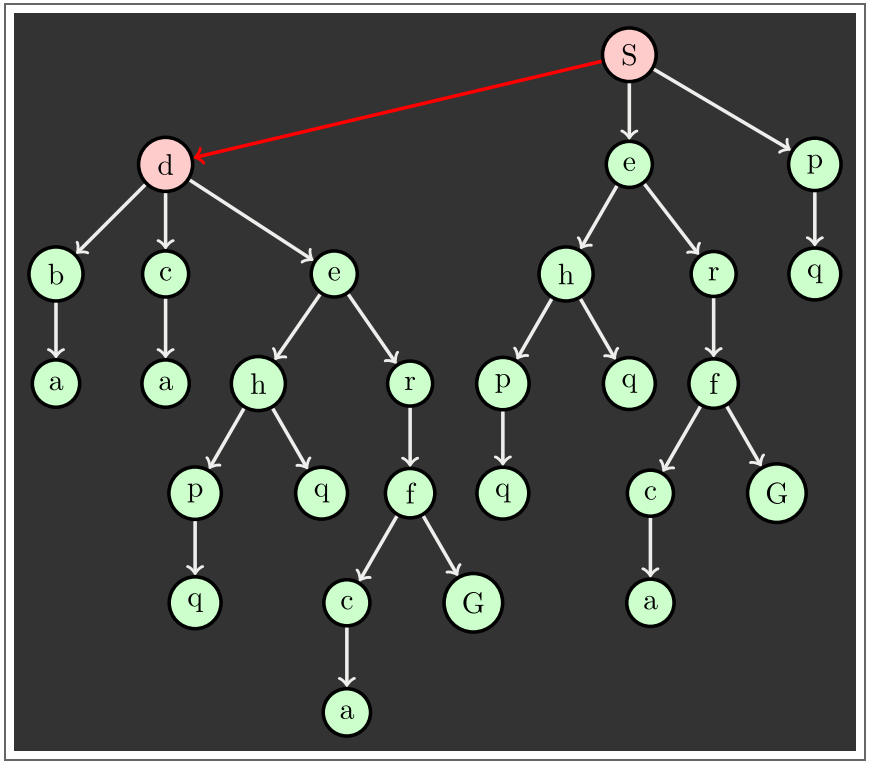
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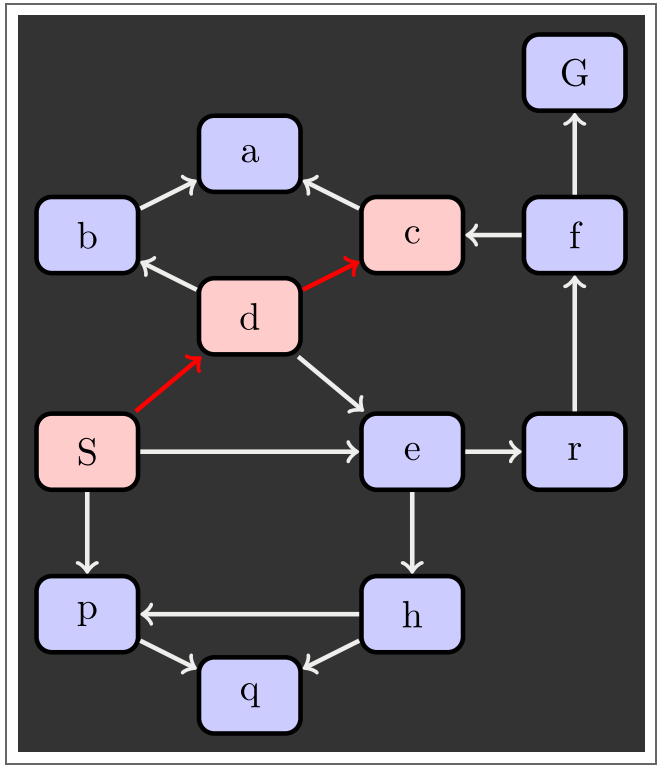
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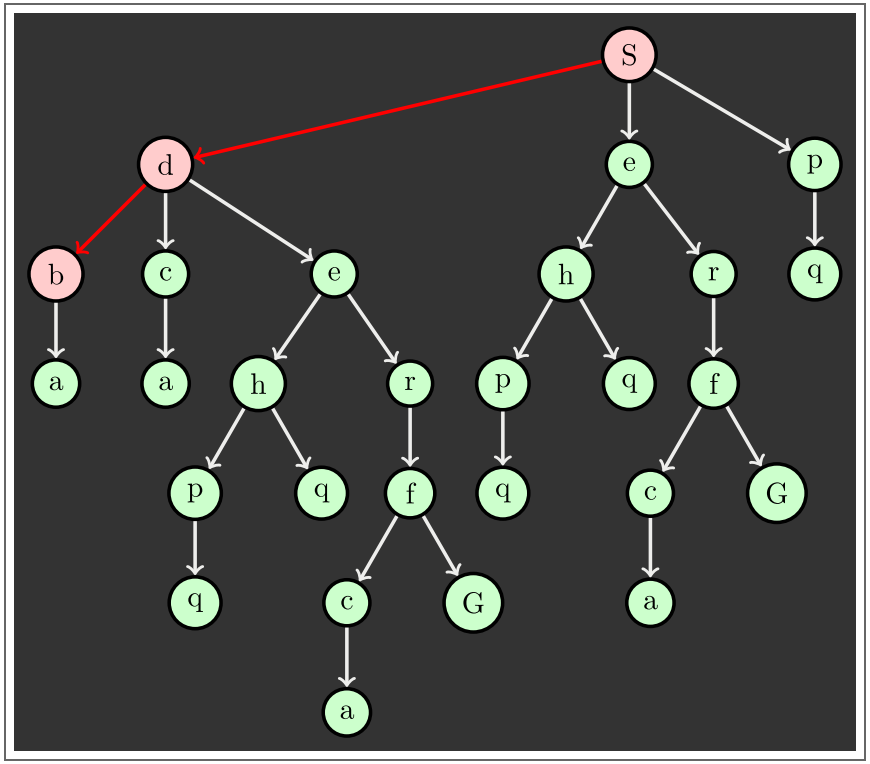
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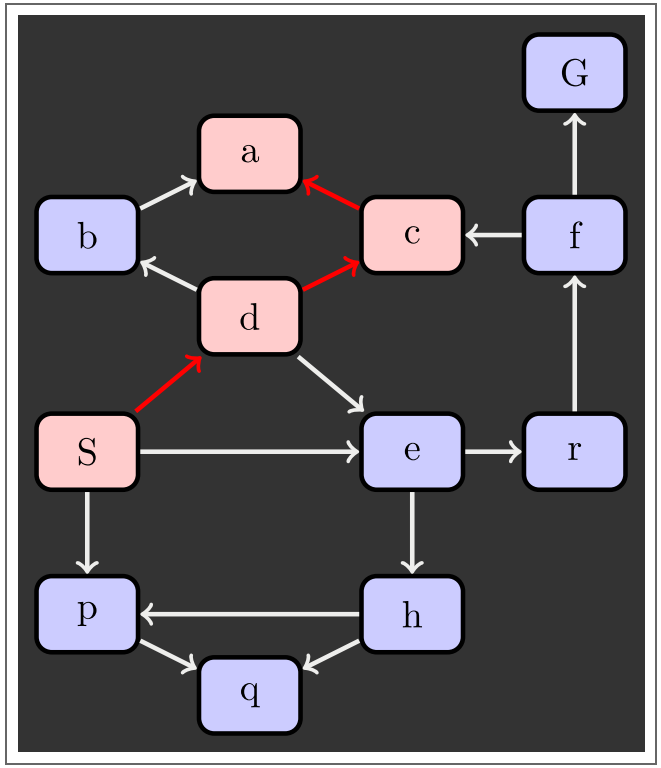
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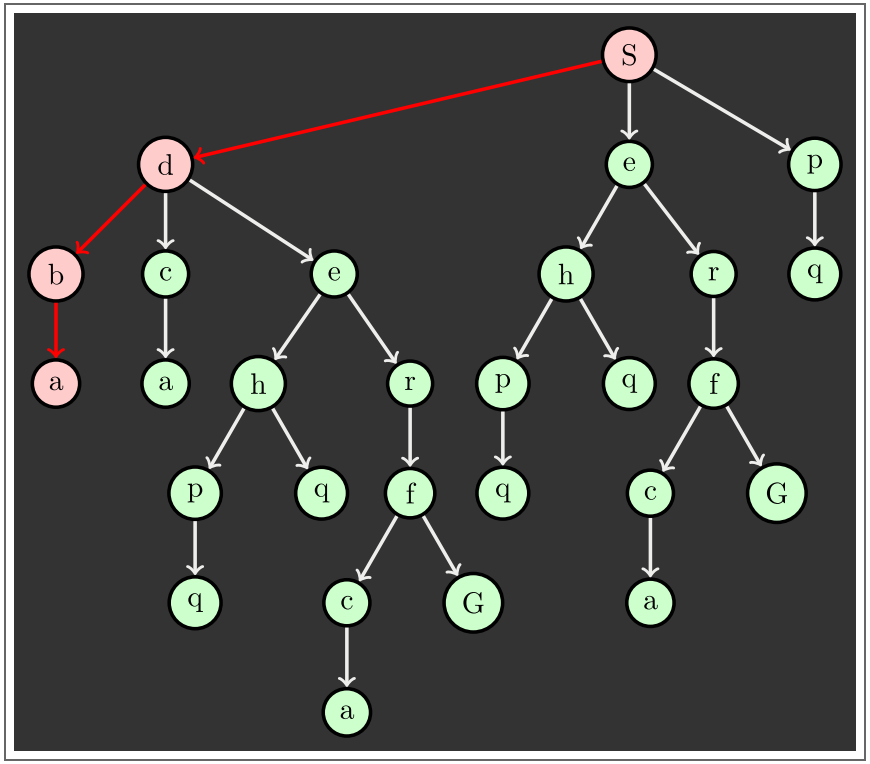
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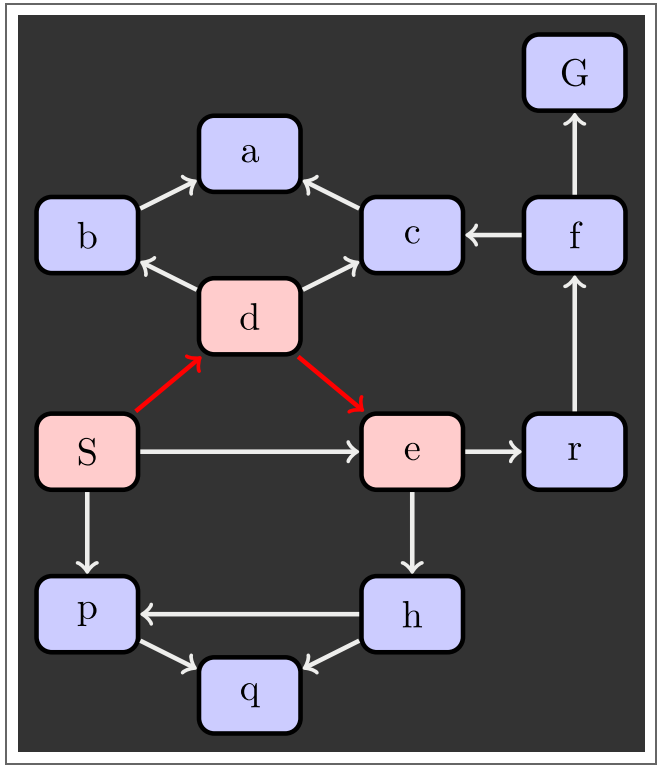
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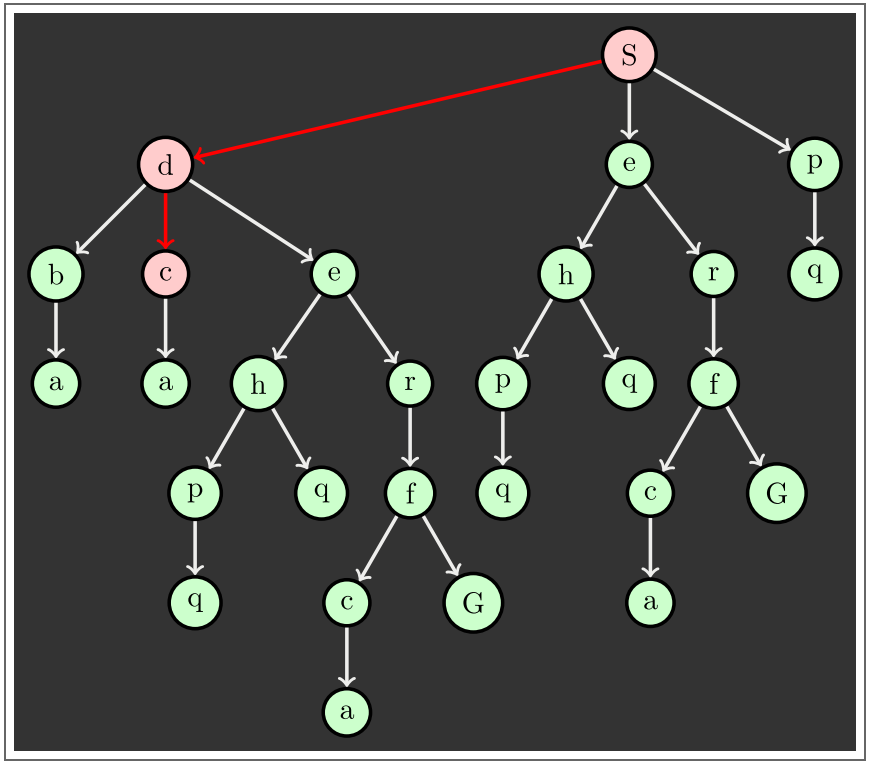
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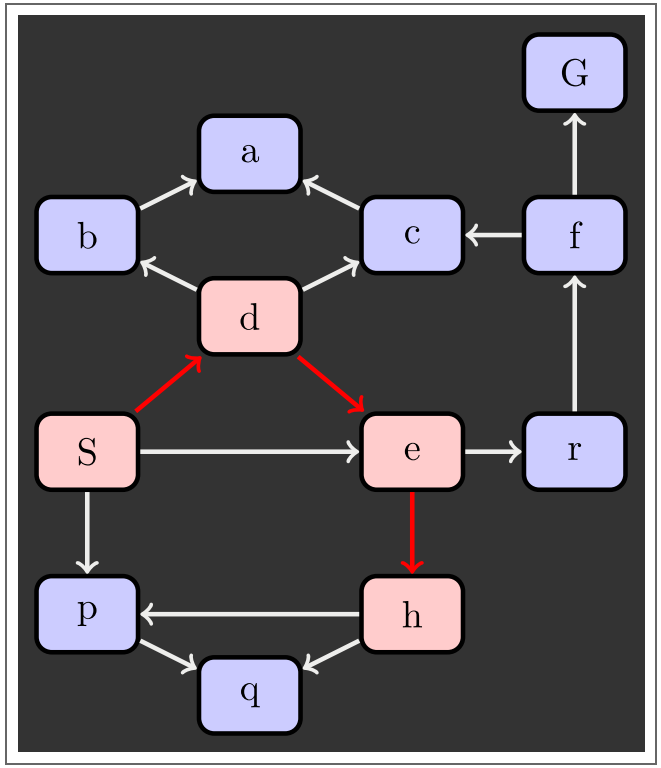
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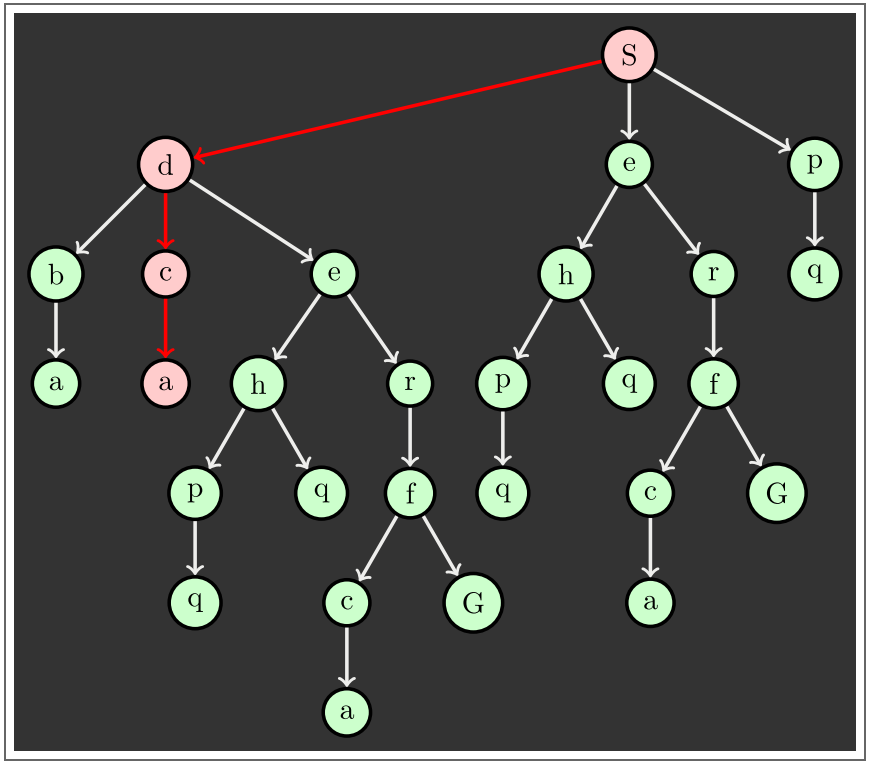
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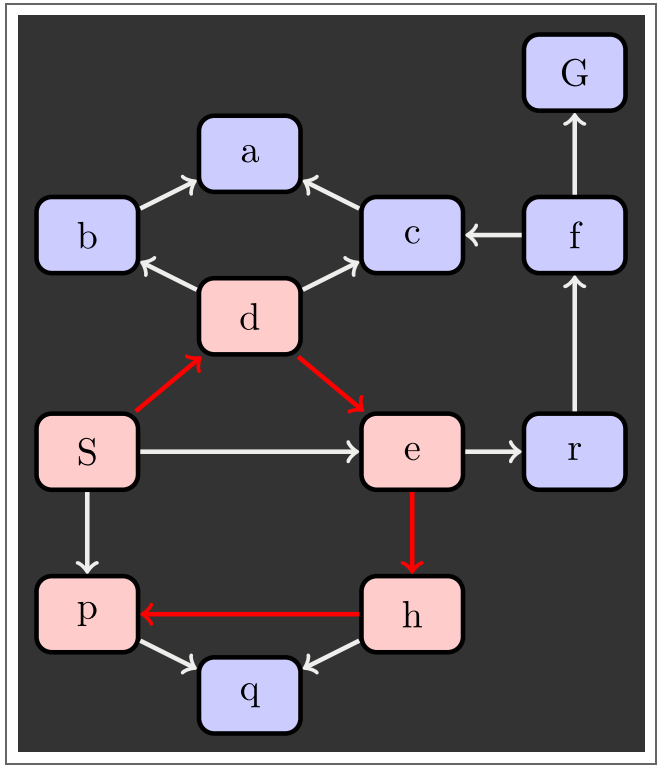
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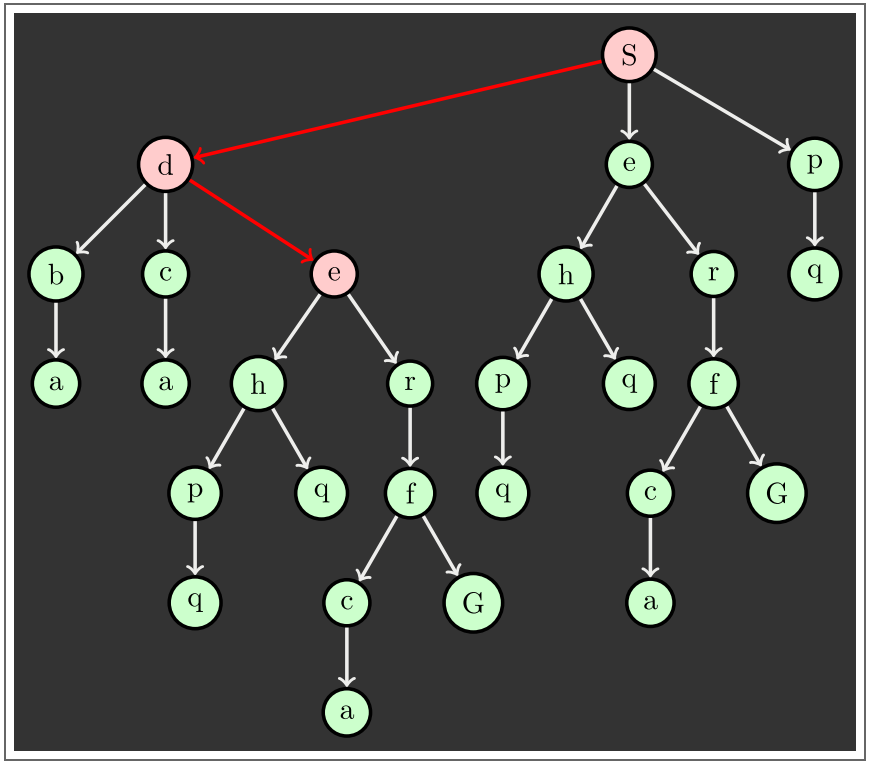
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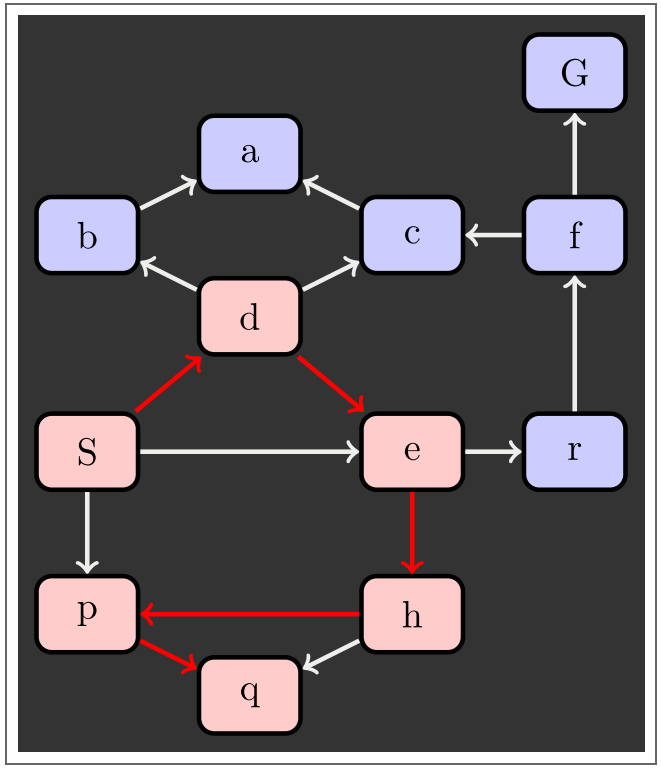
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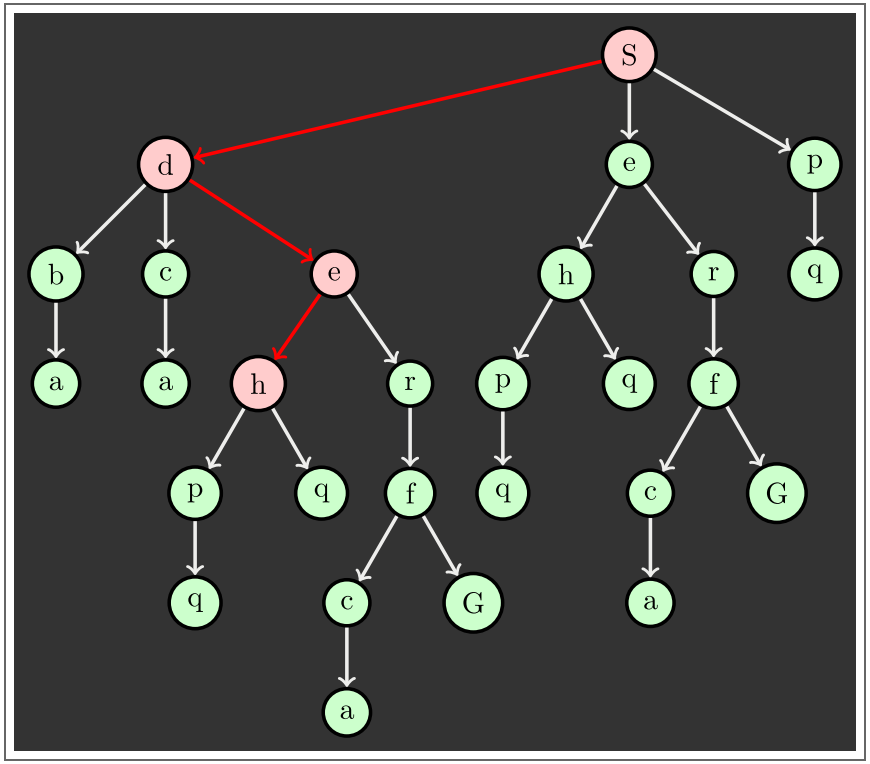
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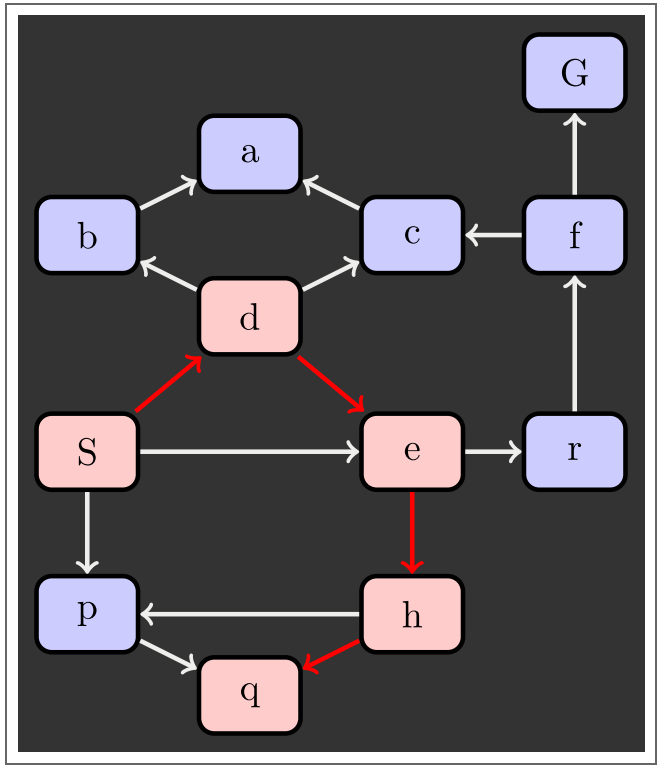
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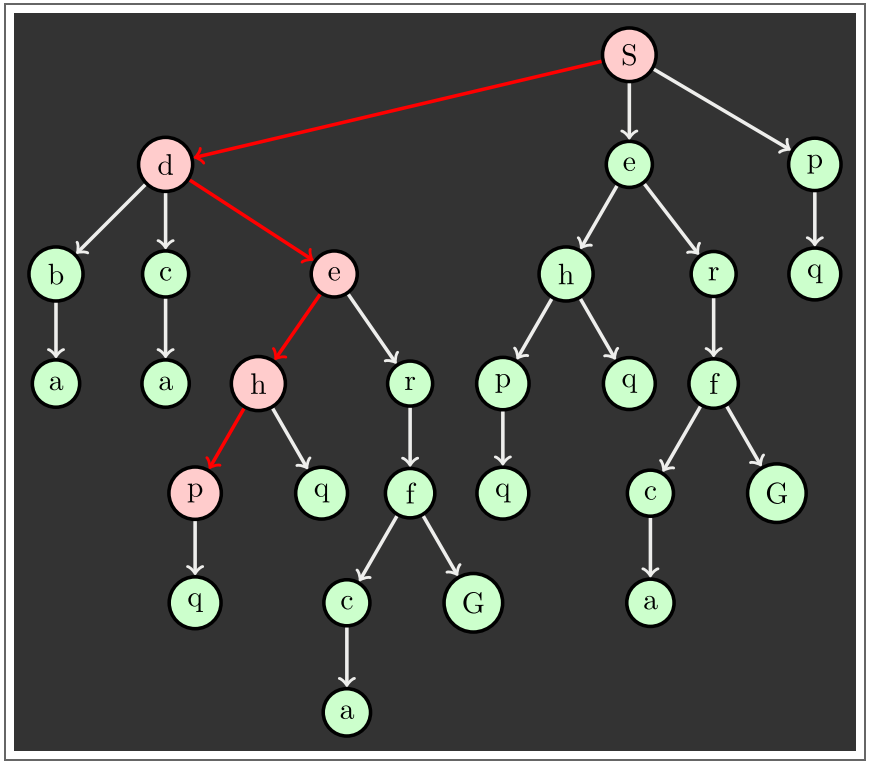
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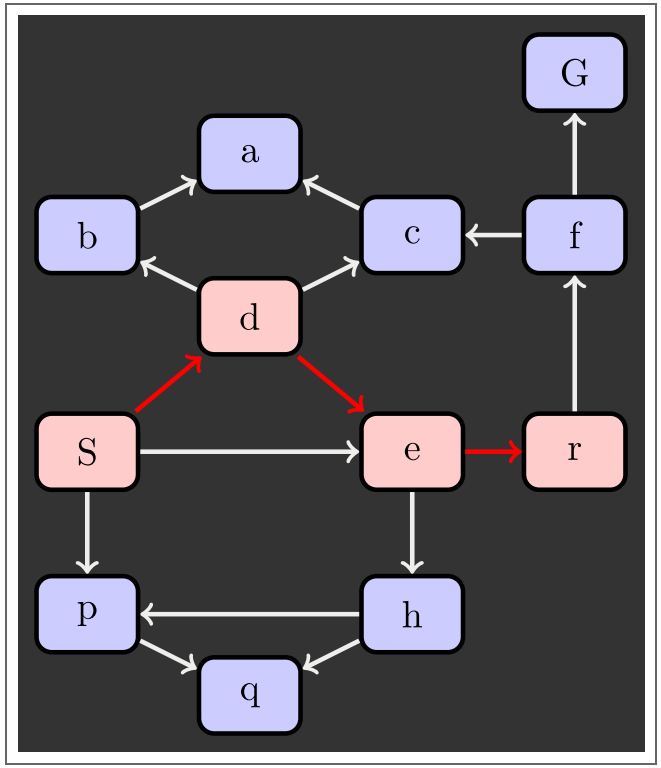
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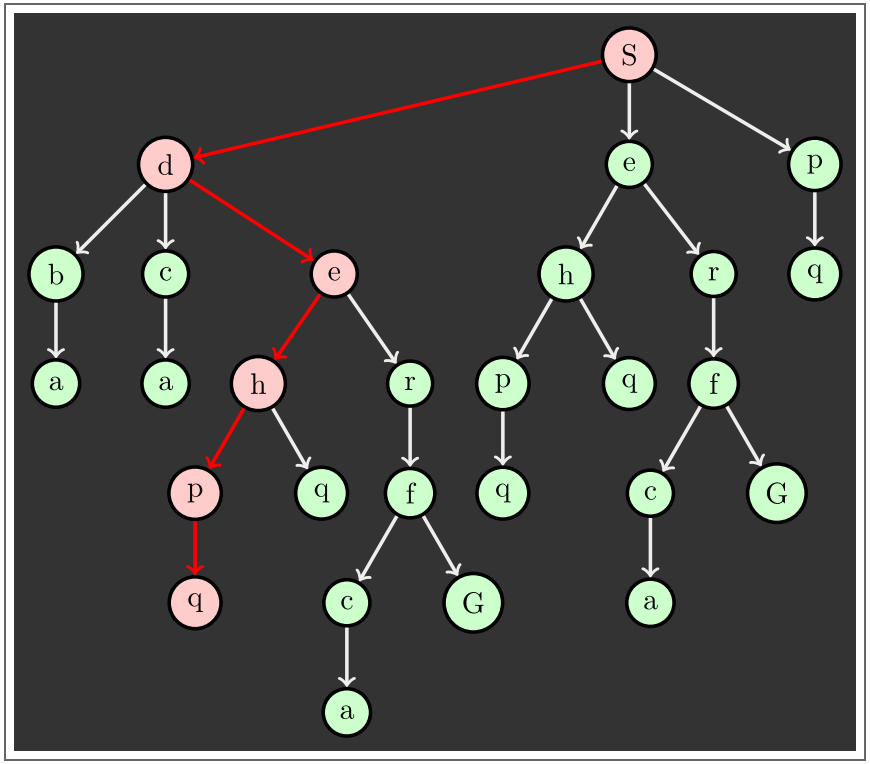
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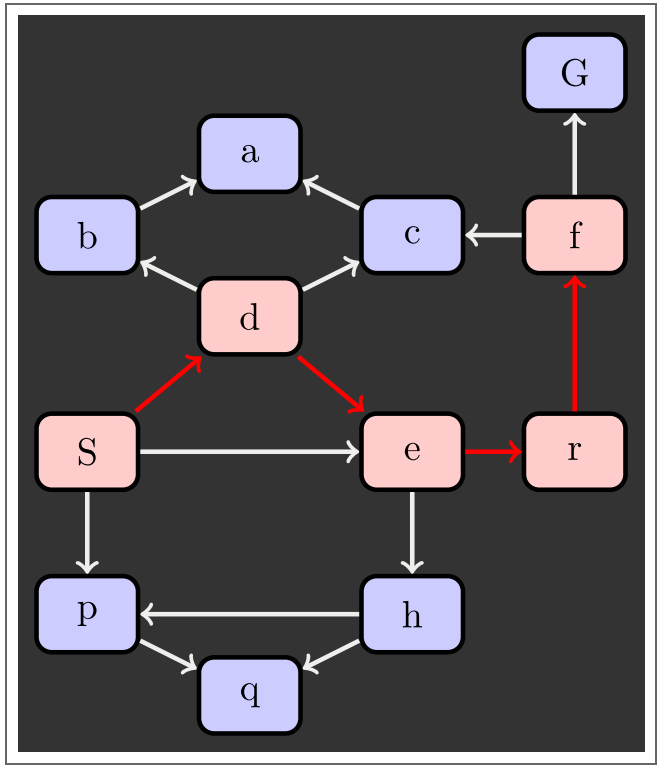
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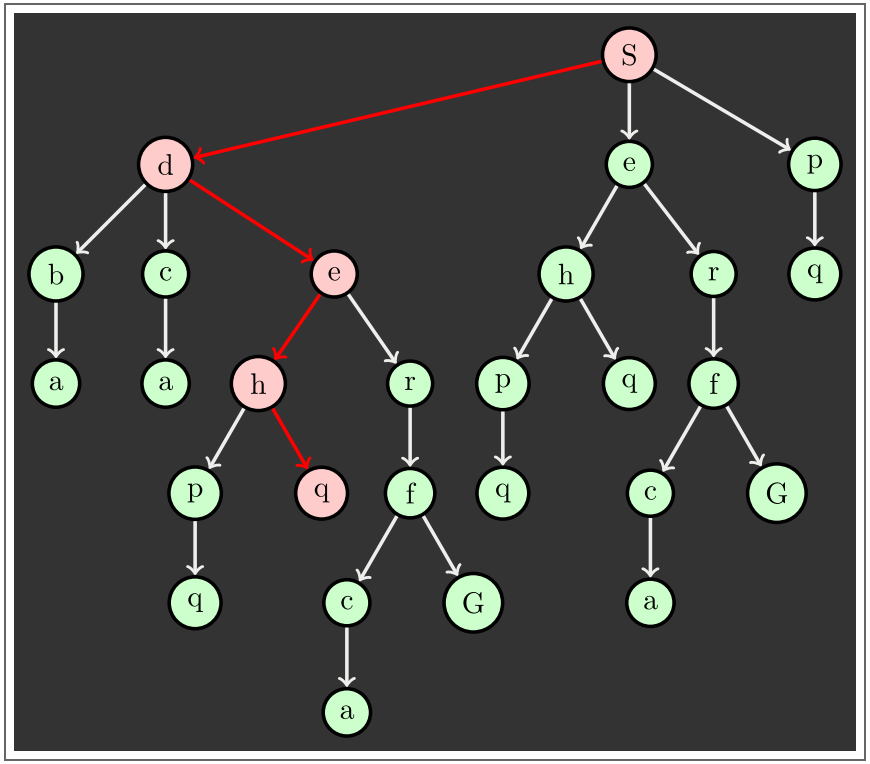
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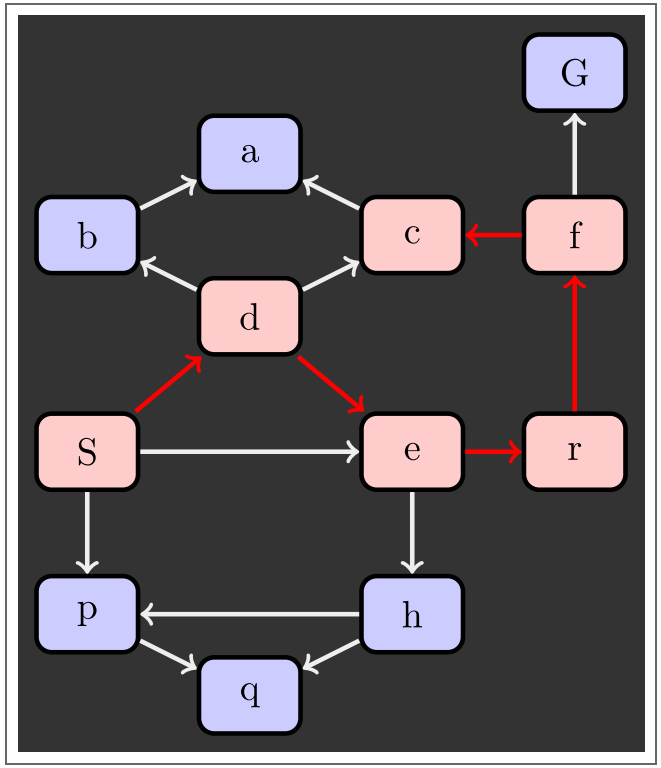
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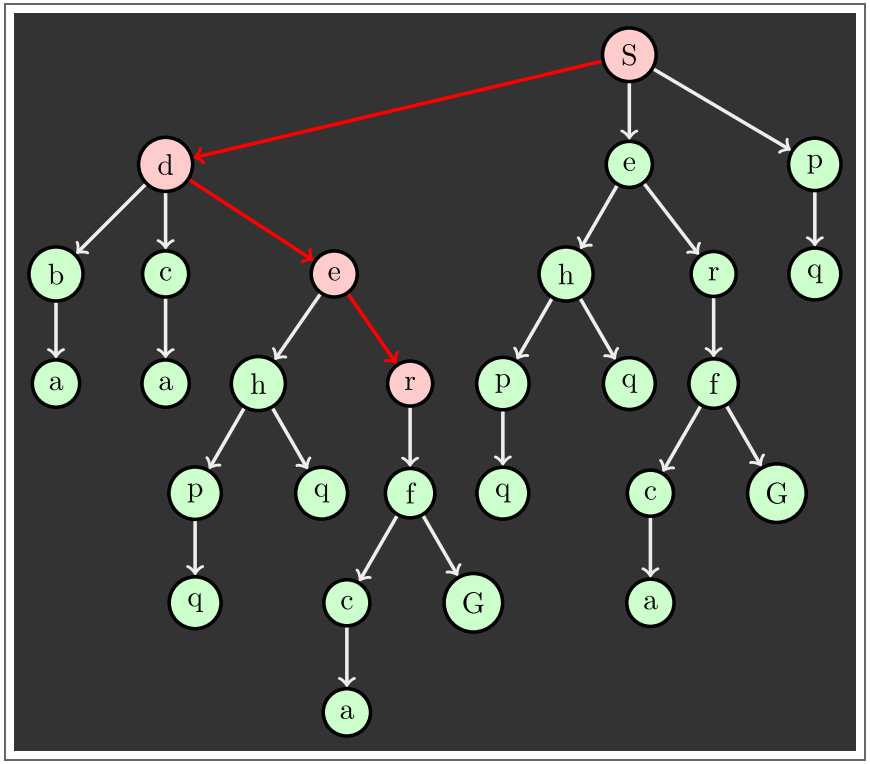
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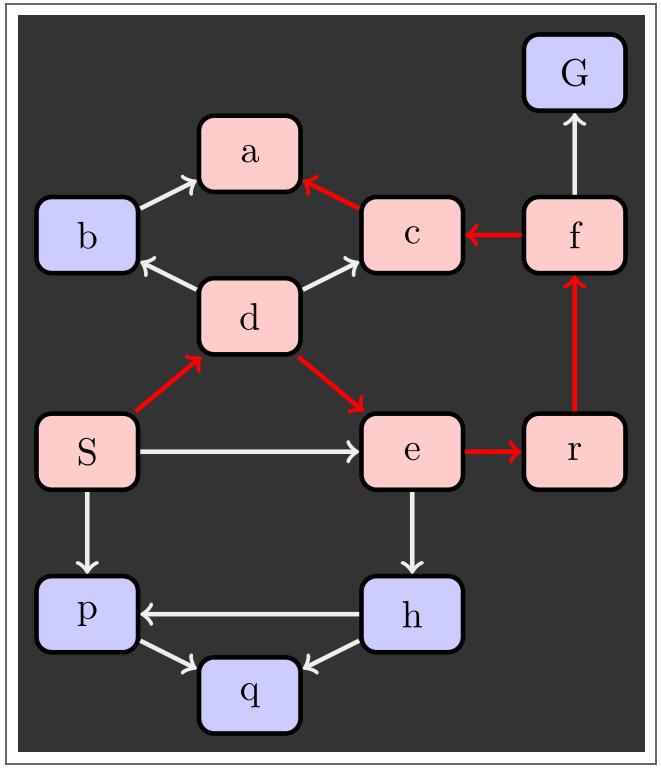
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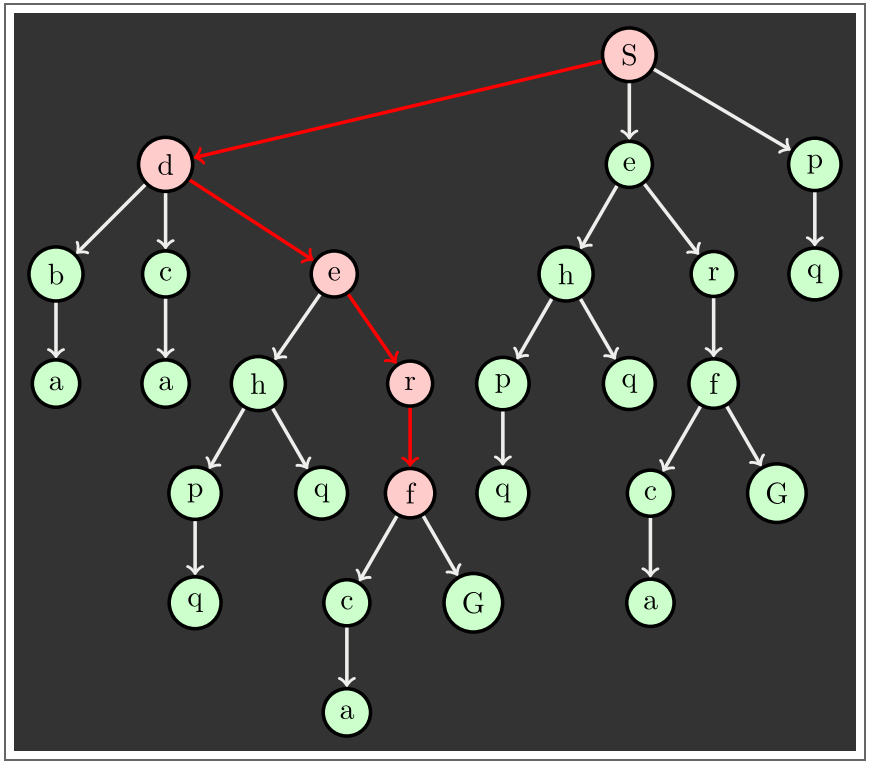
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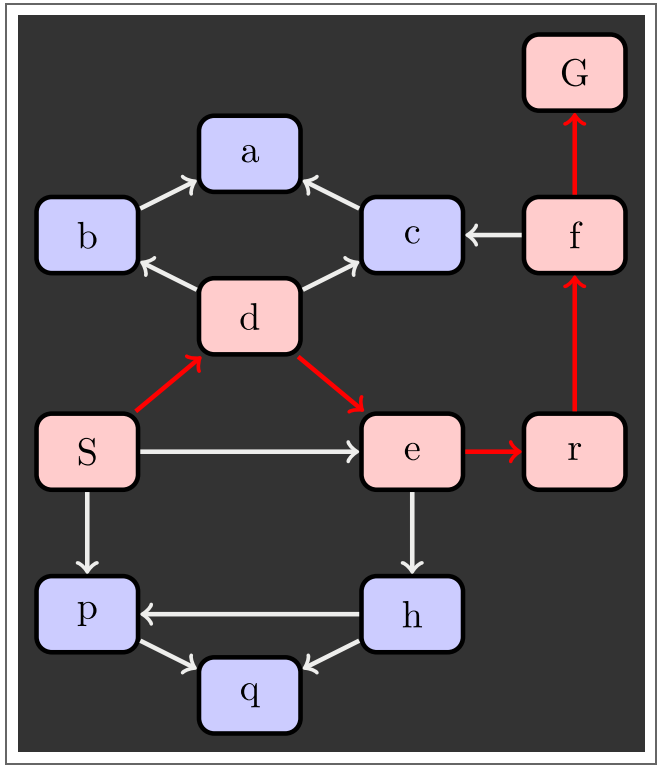
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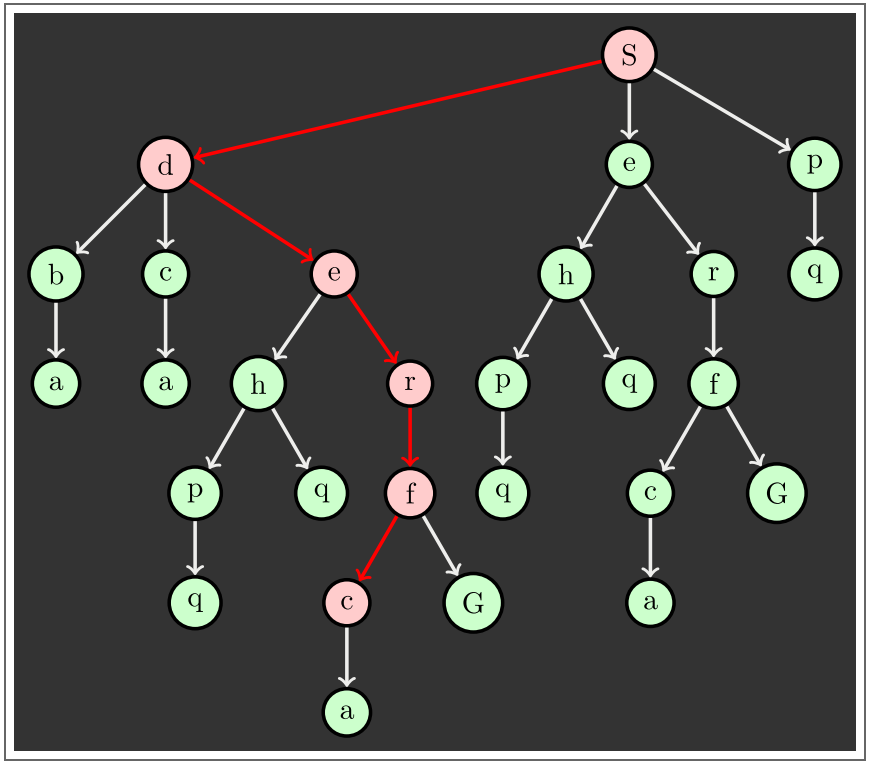
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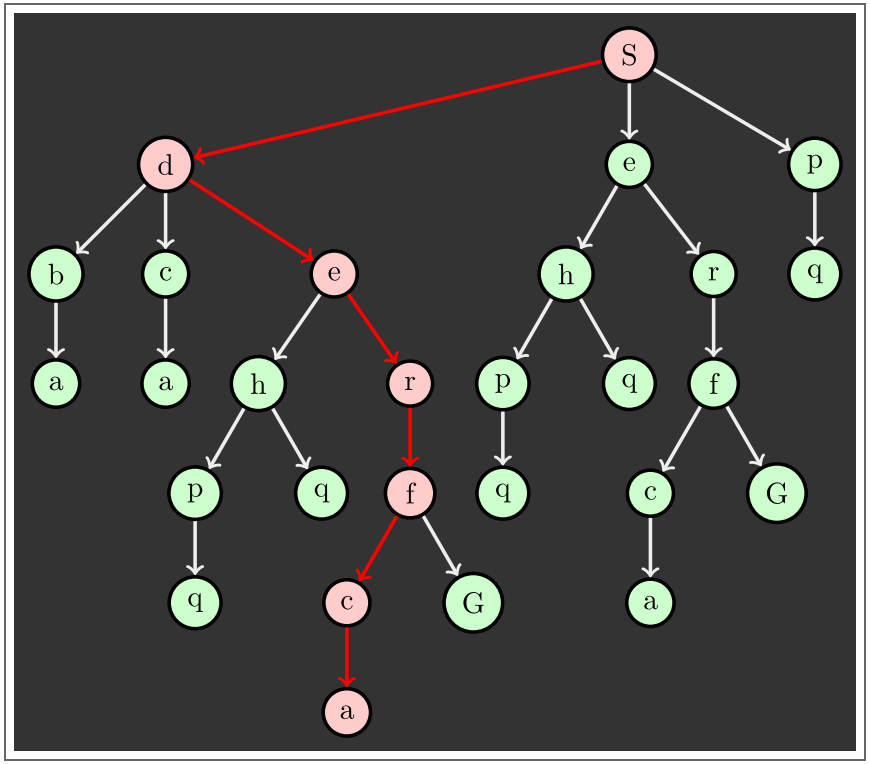
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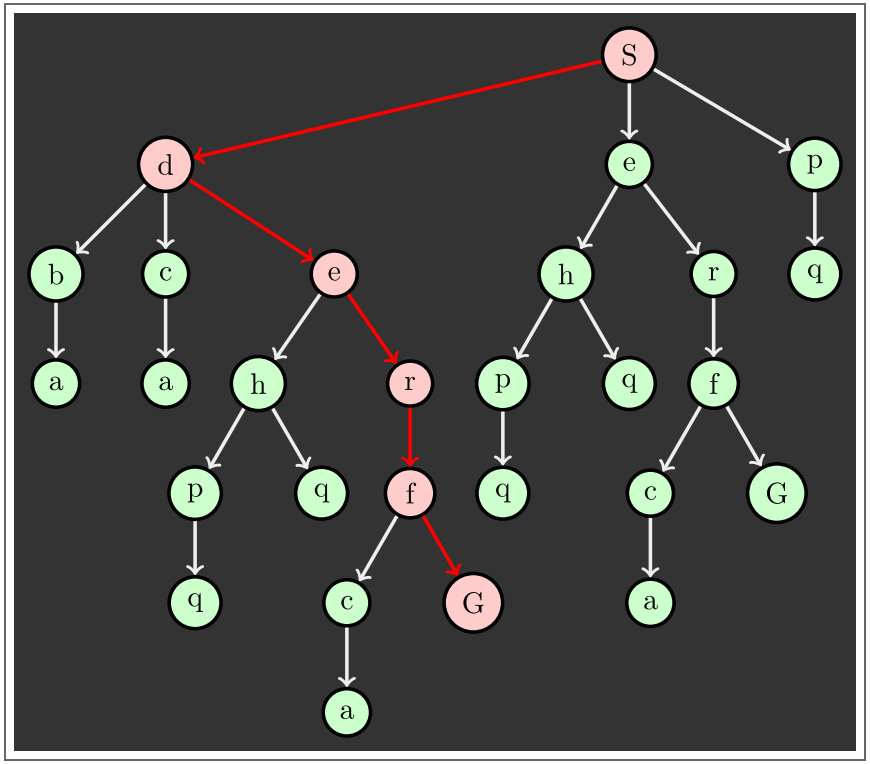
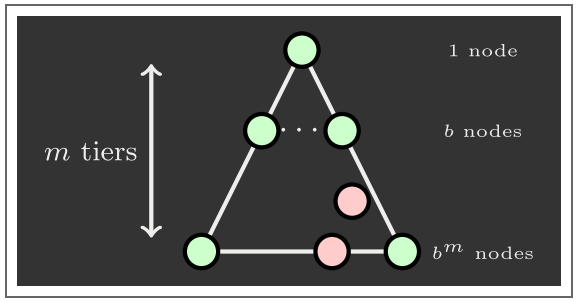


Strategy: expand the deepest node first

Implementation: fringe is a FILO or LIFO stack

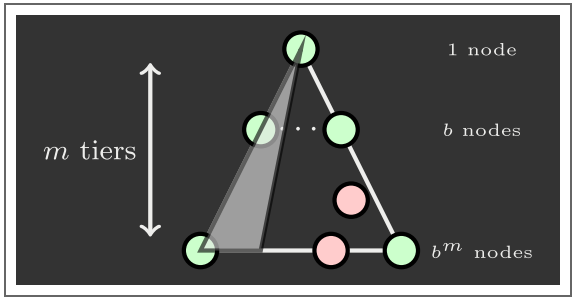
What nodes DFS expand?

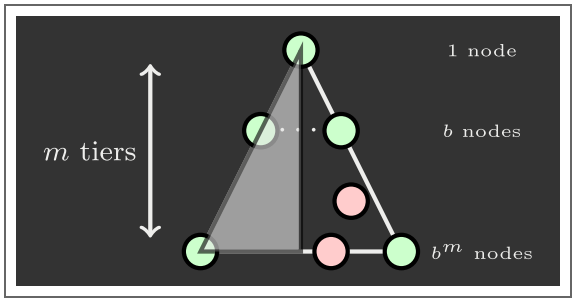
- Some left prefix of the tree.
- Could process the whole tree!

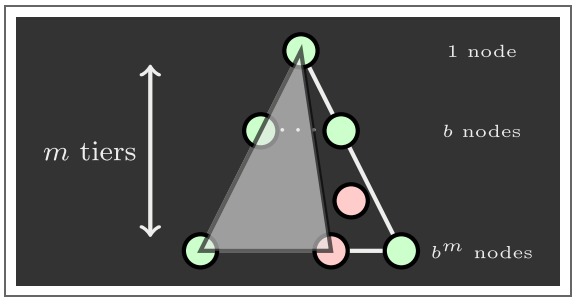


- If m is finite, takes time $\mathcal{O}(b^m)$

BREADTH-FIRST SEARCH (BFS) PROPERTIES







What nodes BFS expand?

- Processes all nodes above shallowest solution
- Let depth of shallowest solution be s
- Search takes time $\mathcal{O}(b^s)$

Is it complete?

- m could be infinite, so only if we prevent cycles (more later)

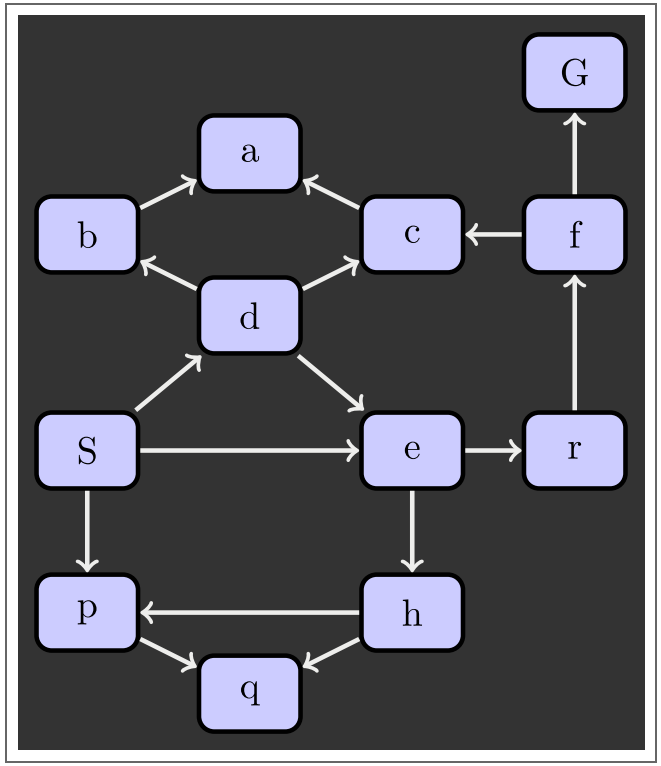
How much space does the fringe take?

- Only has siblings on path to root, so $\mathcal{O}(bm)$.

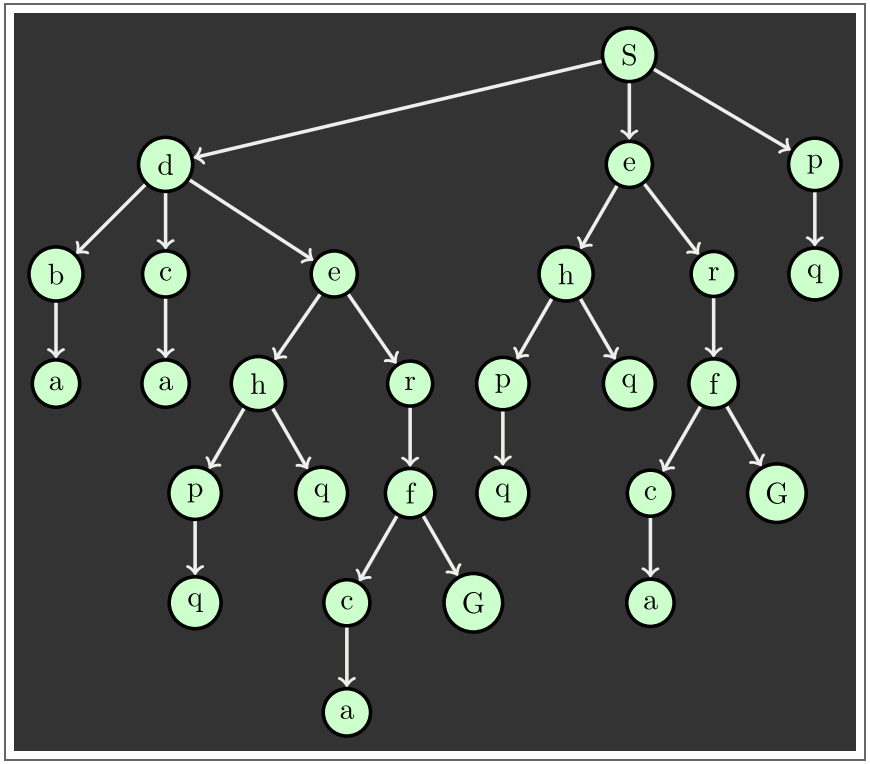
Is it optimal?

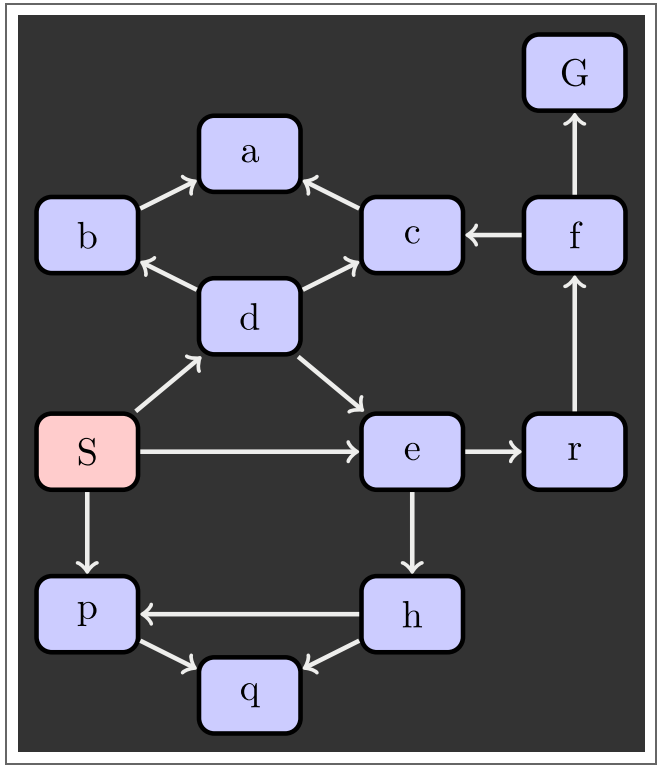
- No, it finds the "leftmost" solution, regardless of depth or cost.

State Space Graph



Search Tree

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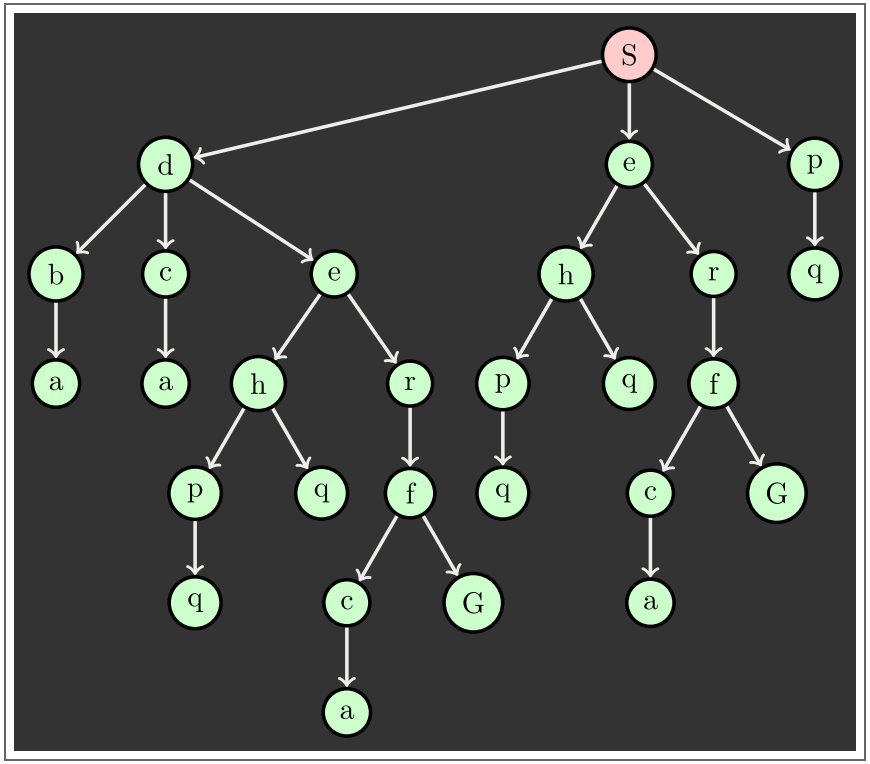
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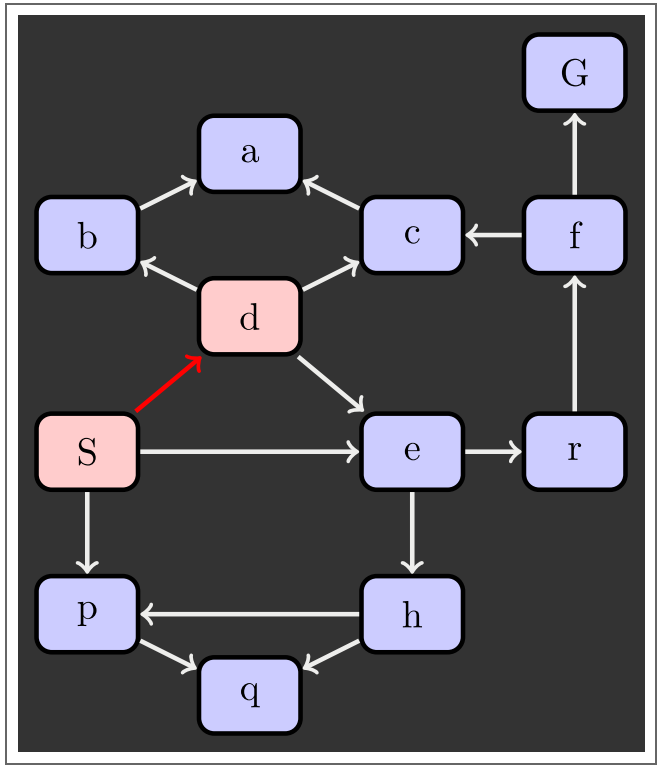
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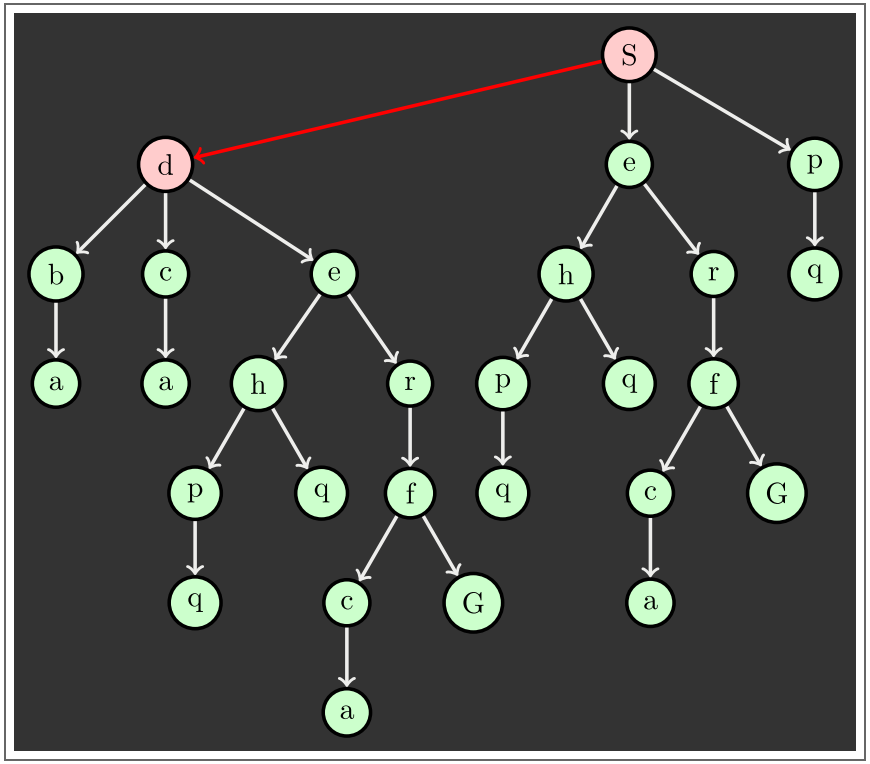
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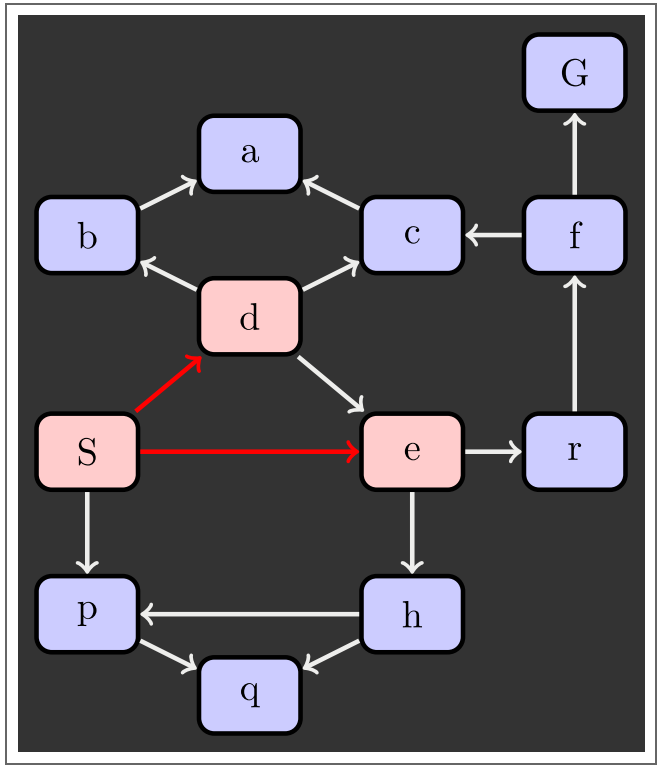
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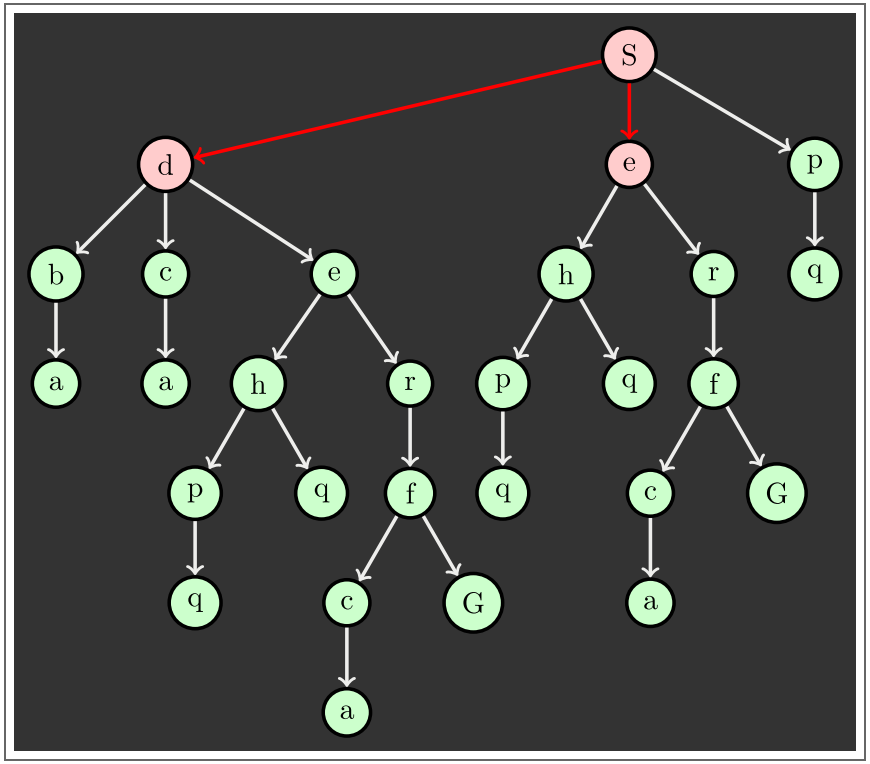
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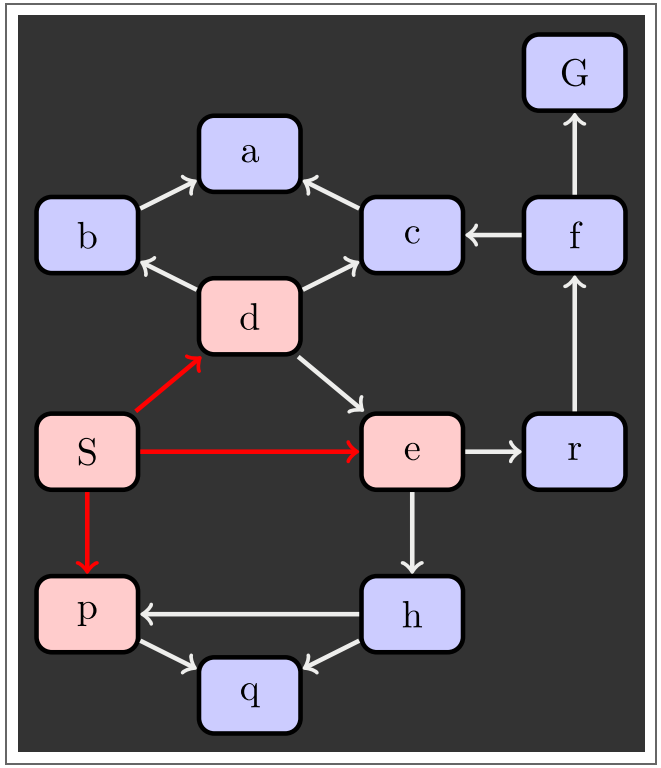
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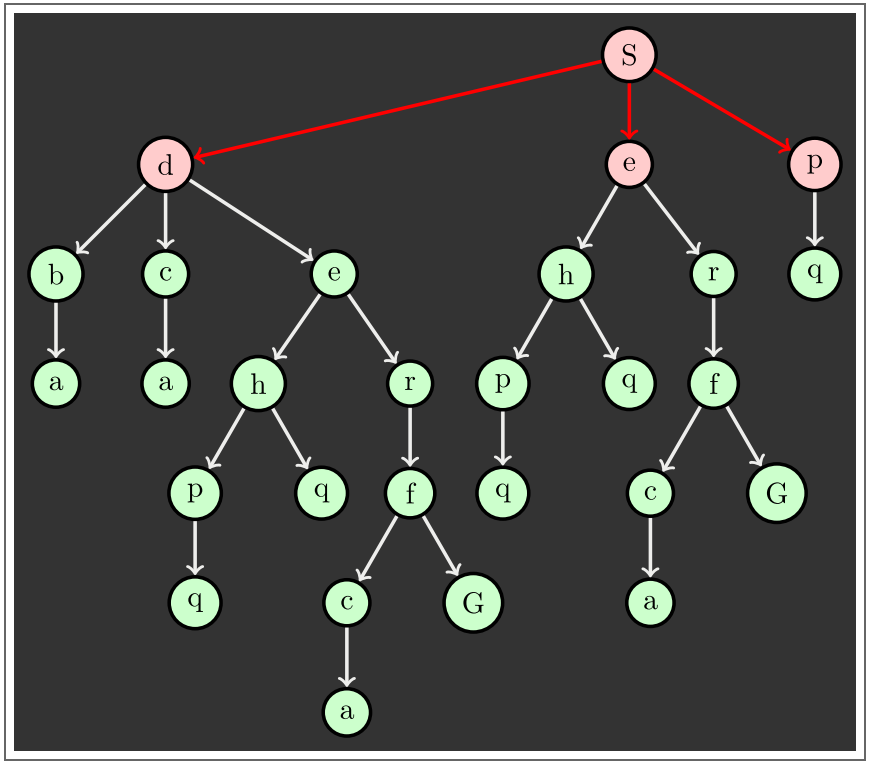
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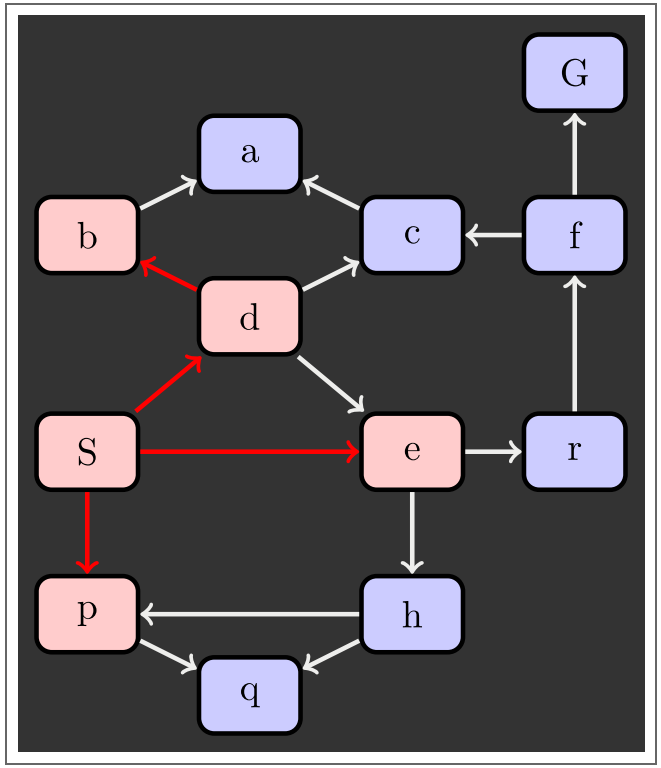
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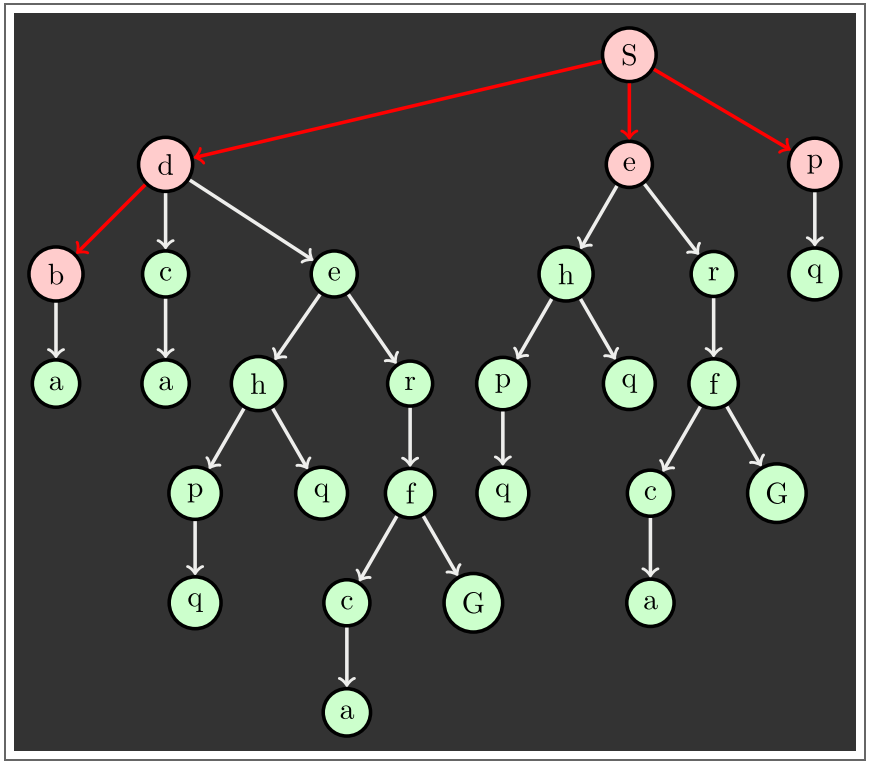
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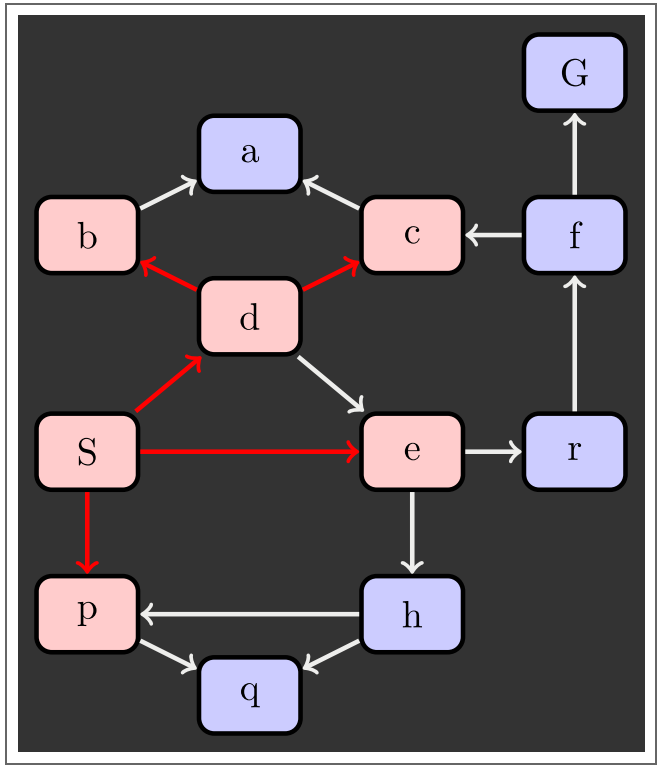
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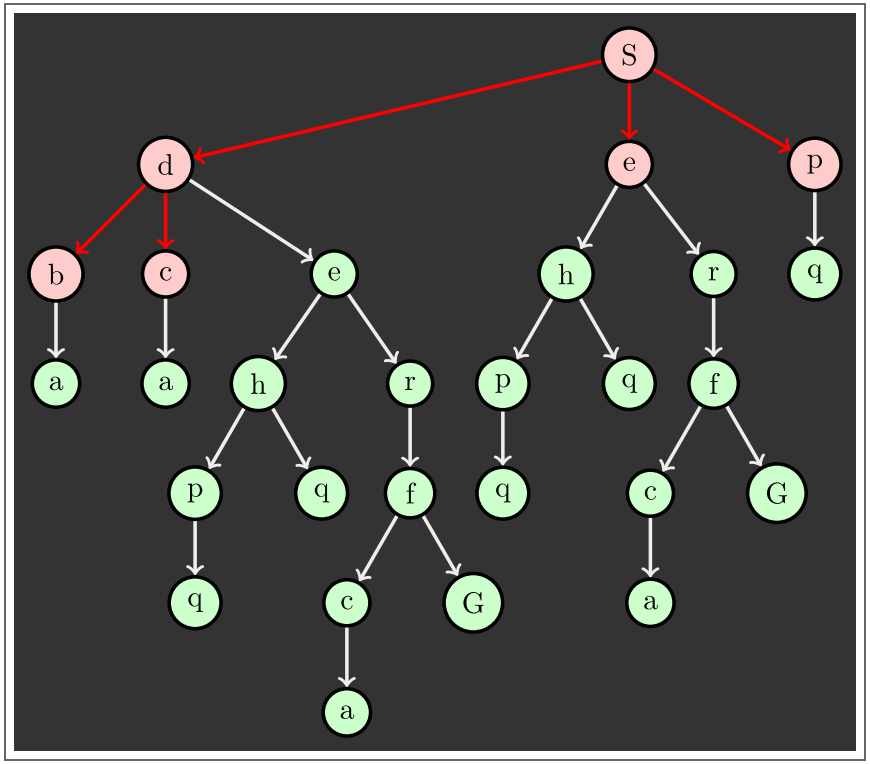
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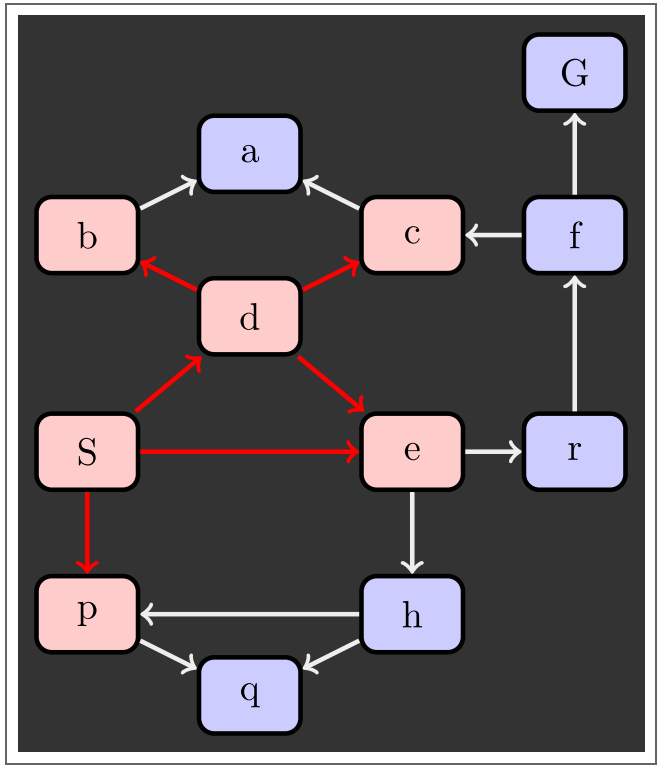
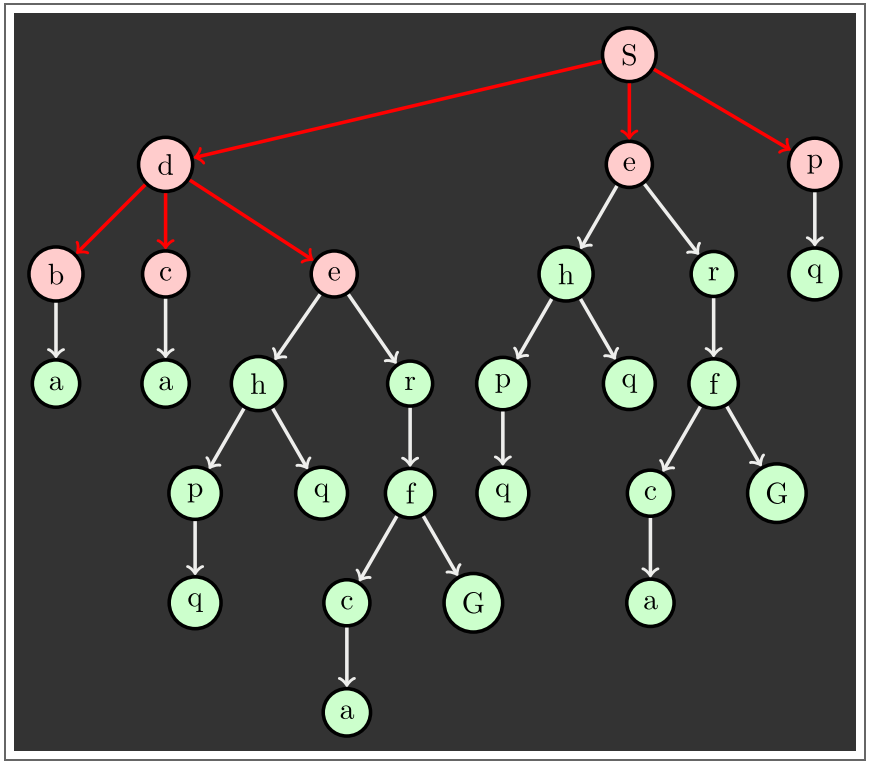




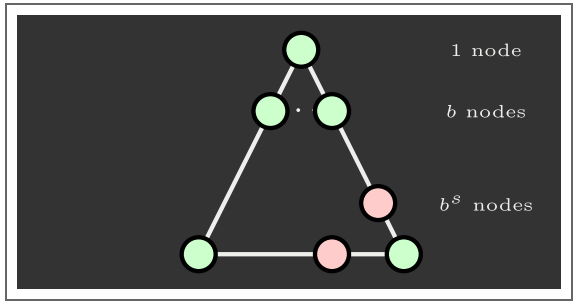
Strategy: expand the shallowest node first

Implementation: fringe is a FIFO queue

How much space does the fringe take?

- Roughly the last tier, so $\mathcal{O}(b^s)$.

Is it complete?



- s must be finite if a solution exists, so yes!

  Is it optimal?

- Only if costs are all 1 (more on costs later)

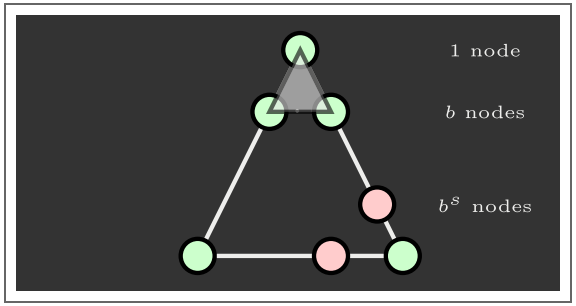
ITERATIVE DEEPENING

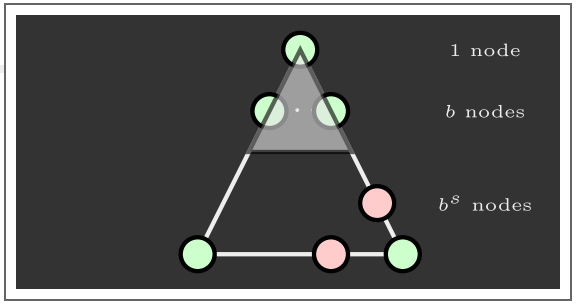
Idea: get the space advantage of DFS with the time / shallow-solution advantage of BFS.

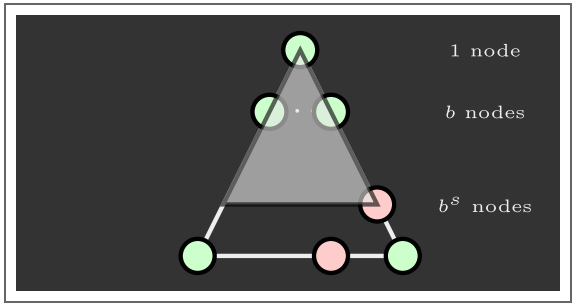
- Run a DFS with depth limit 1. If no solution . . .
- Run a DFS with depth limit 2. If no solution . . .
- Run a DFS with depth limit 3. If no solution . . .

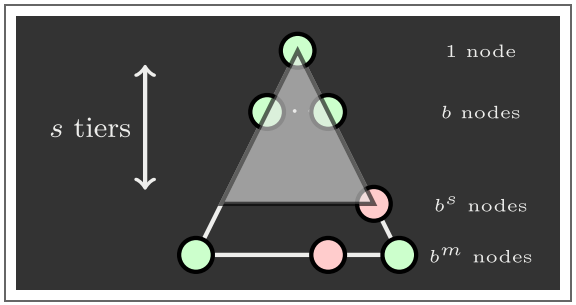
  Is this not wastefully redundant?

- Generally most work happens in the deepest level searched, so it is not so bad.

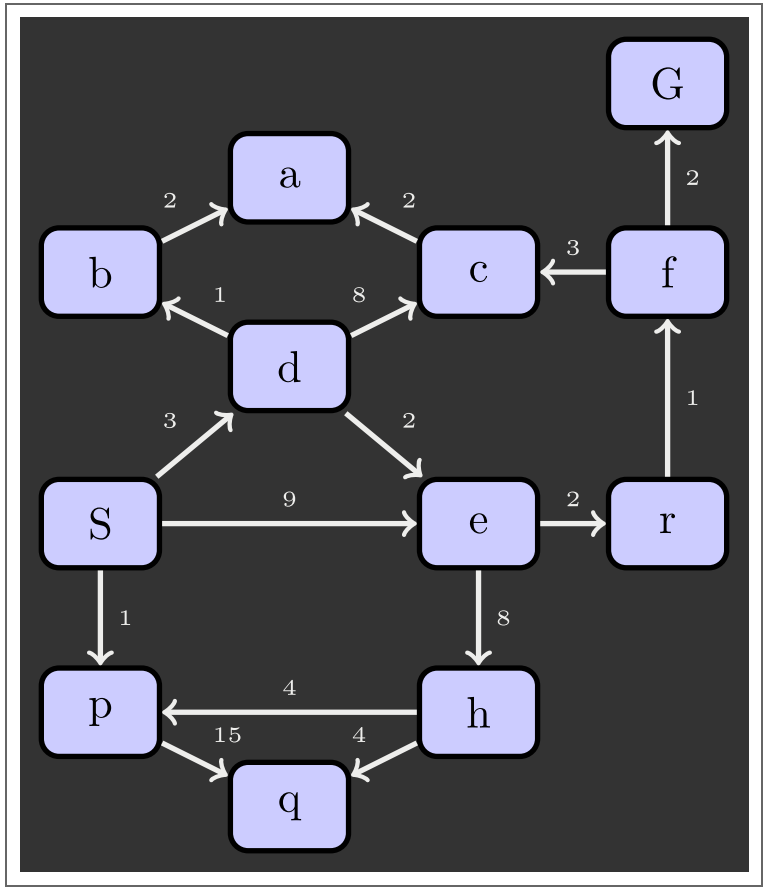








COST SENSITIVE SEARCH

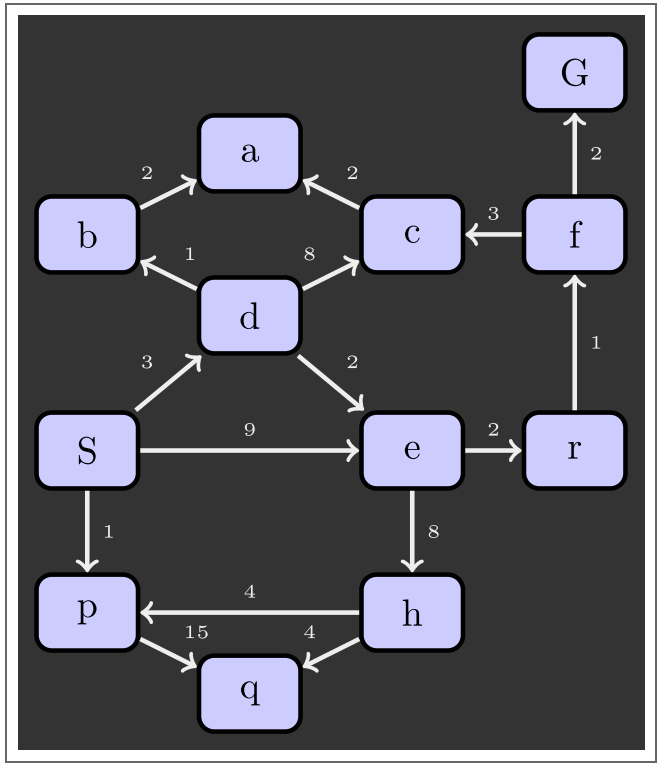


BFS finds the shortest path in terms of number of actions. It does not find the least-cost path. We will now cover a similar algorithm which does find the least-cost path.

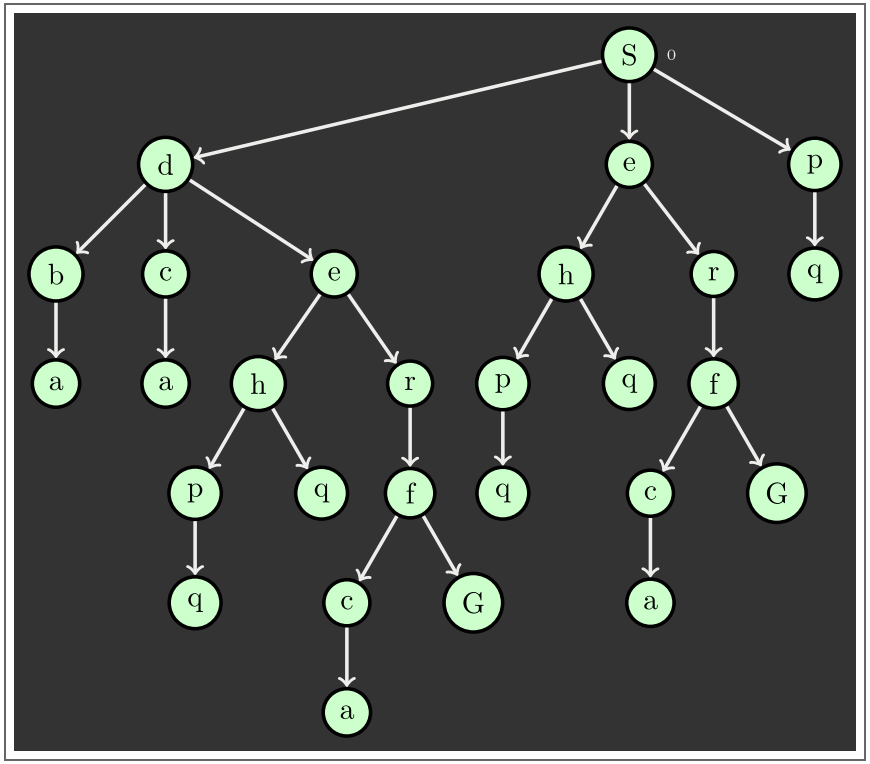
UNIFORM COST SEARCH

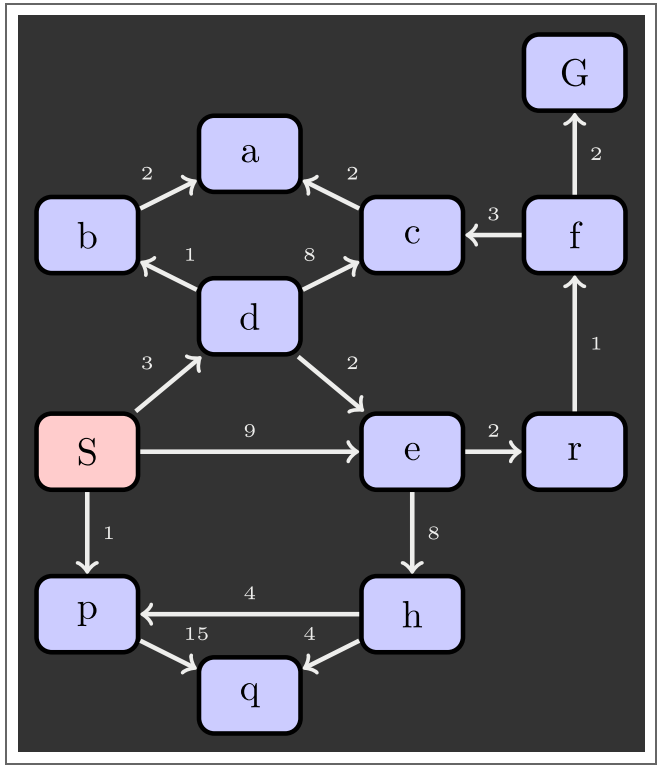
UNIFORM COST SEARCH (UCS)

State Space Graph



Search Tree

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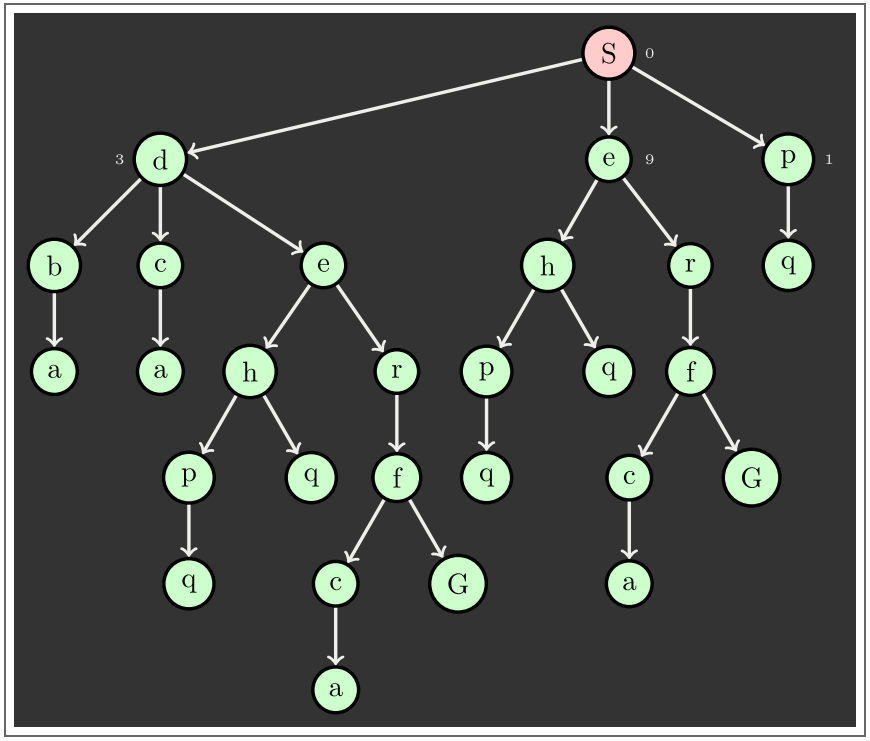
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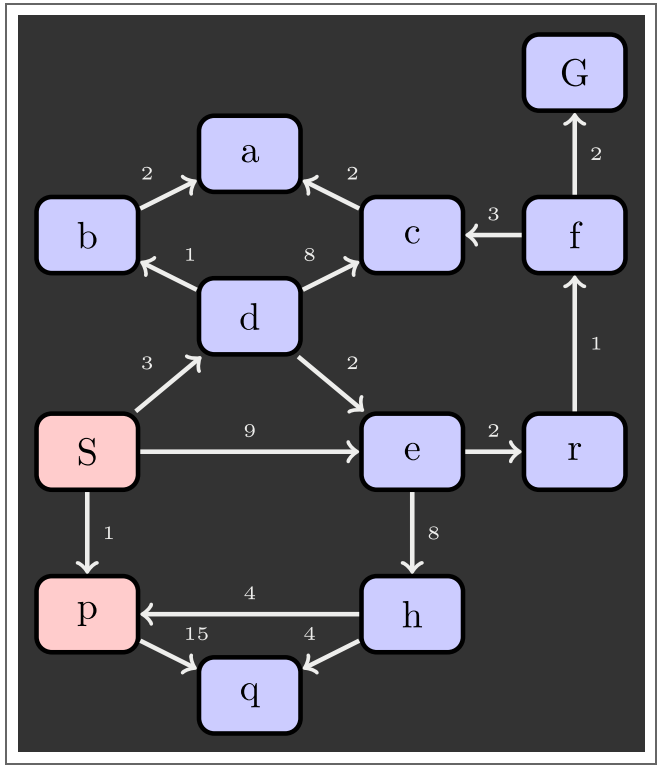
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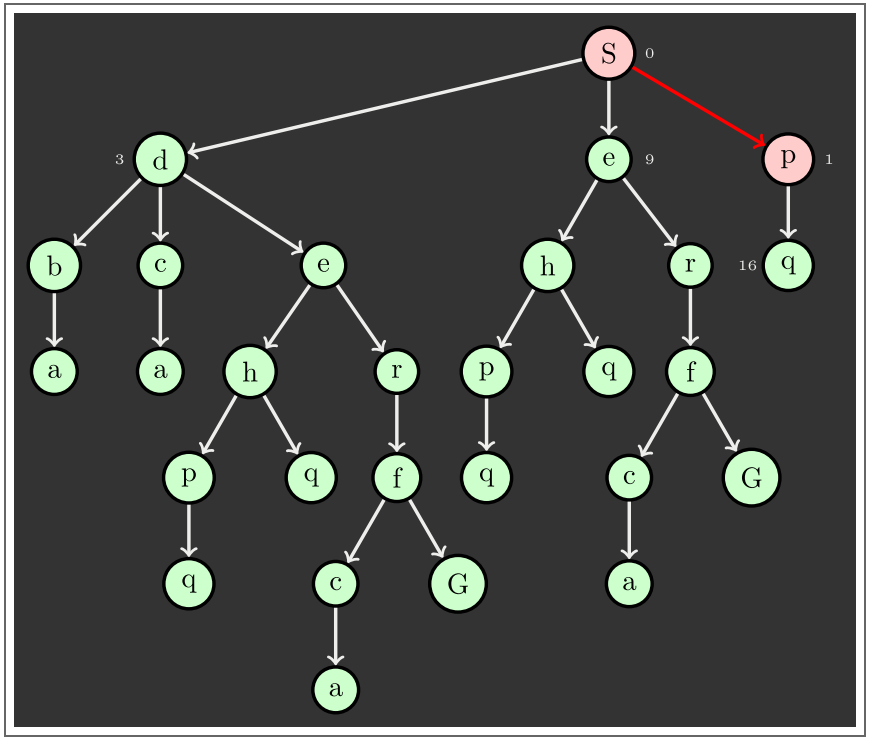
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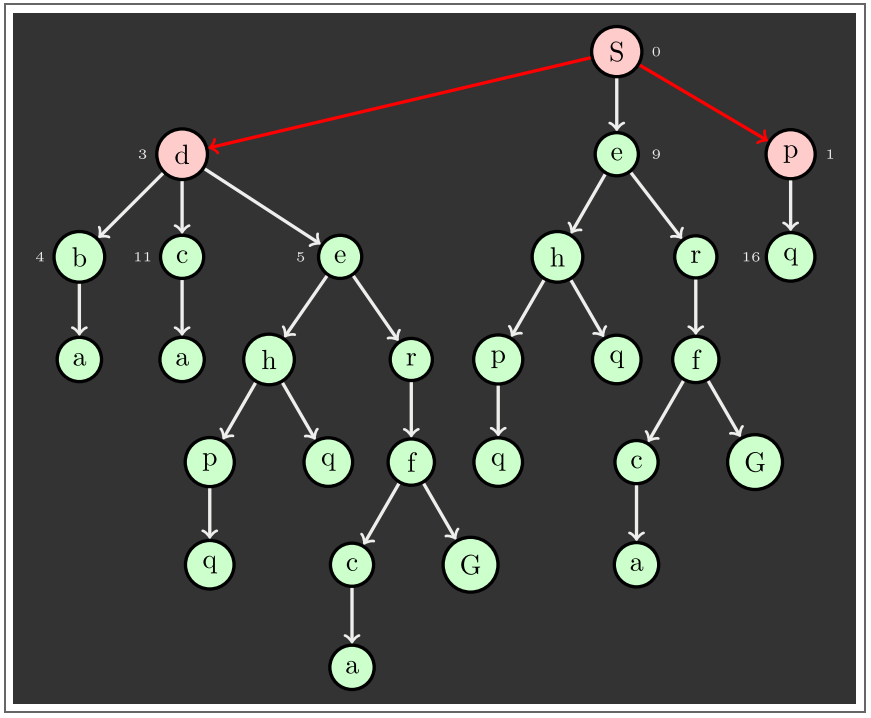
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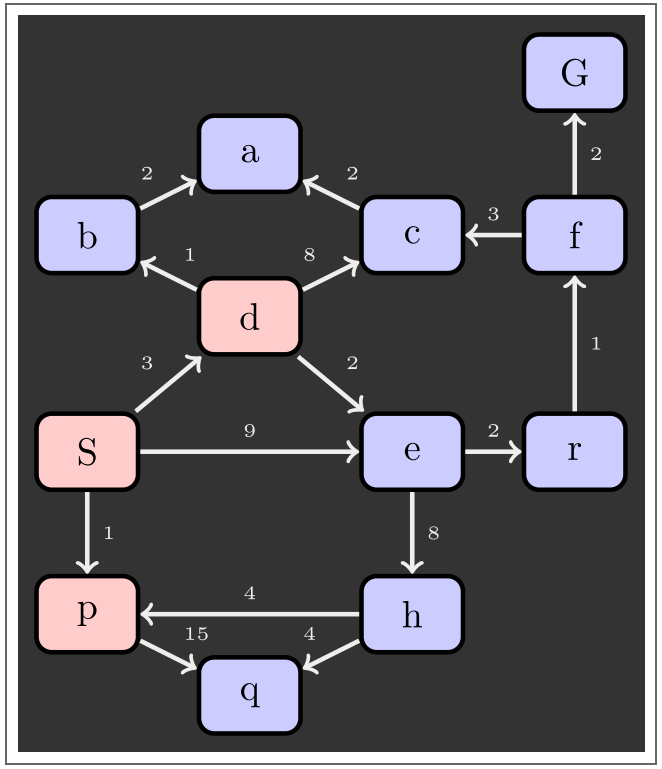
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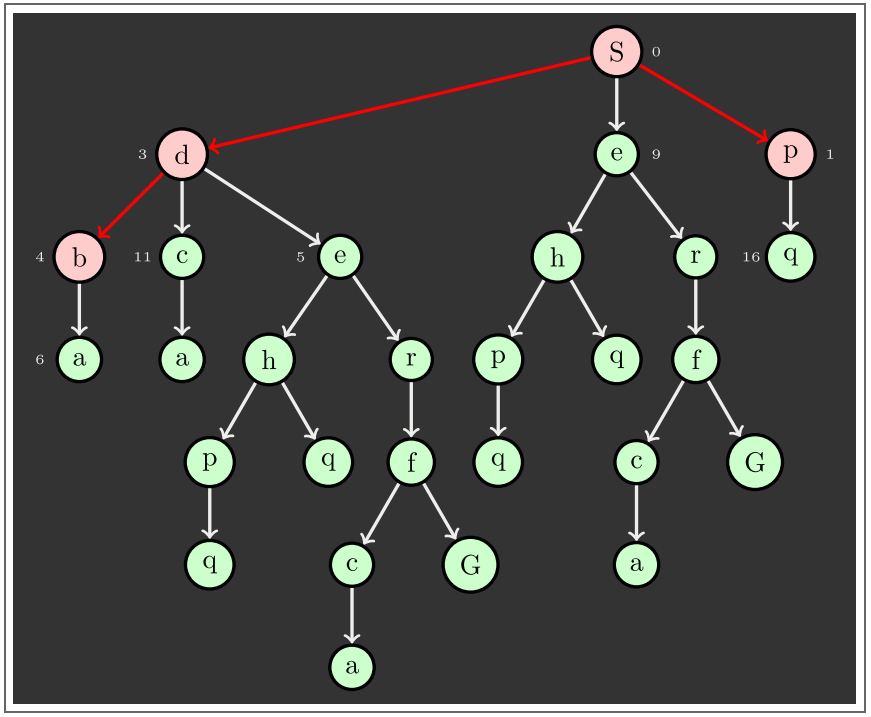
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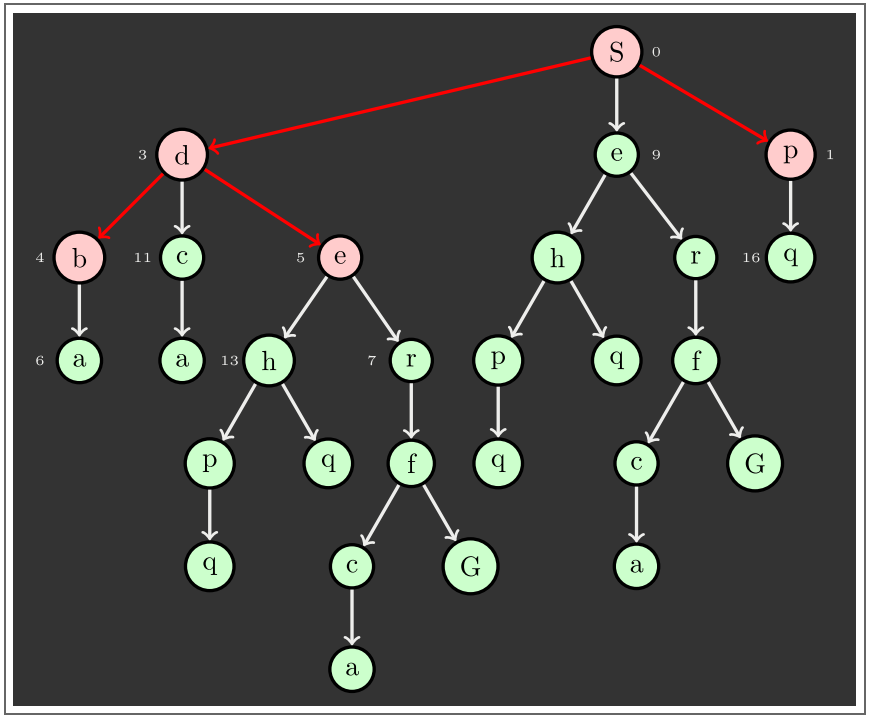
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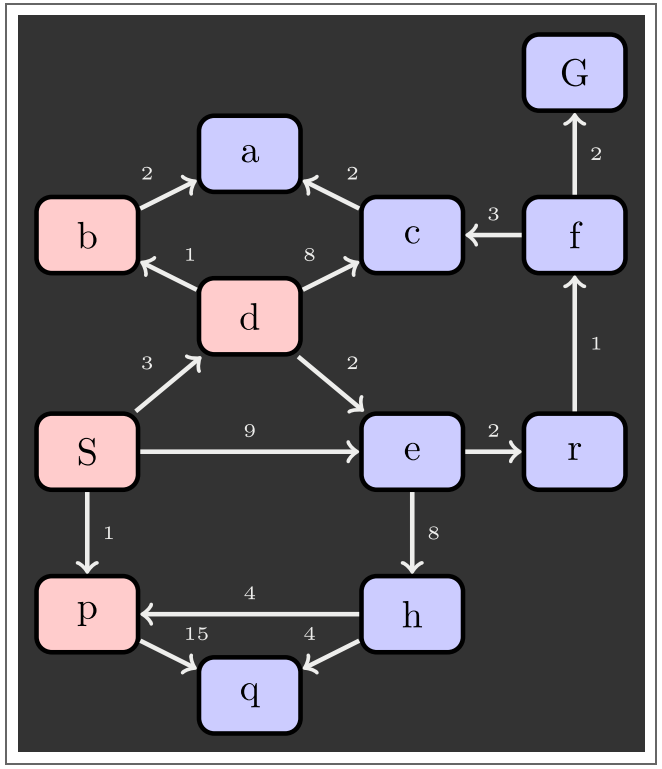
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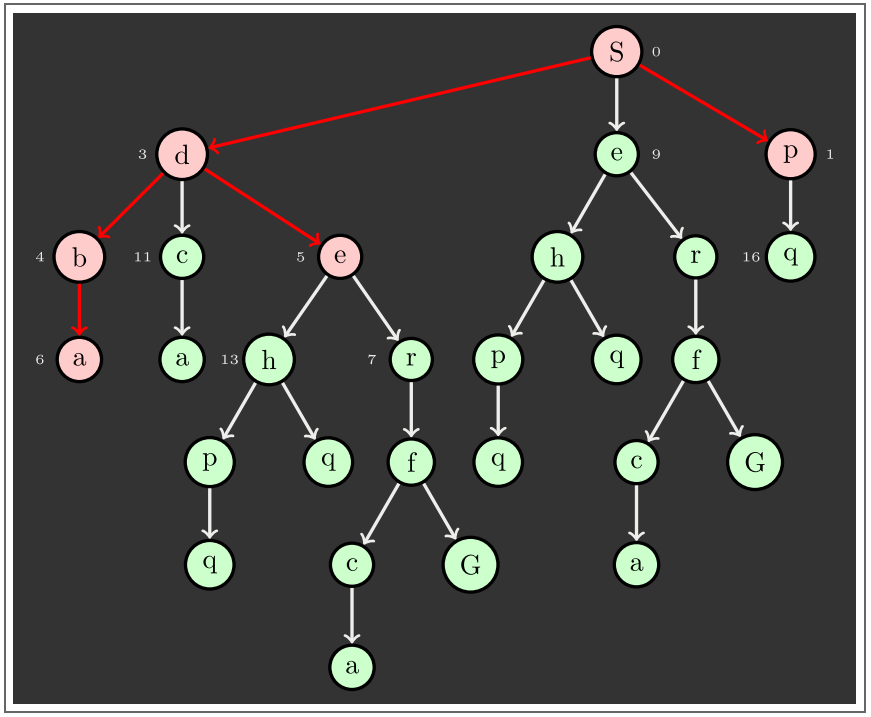
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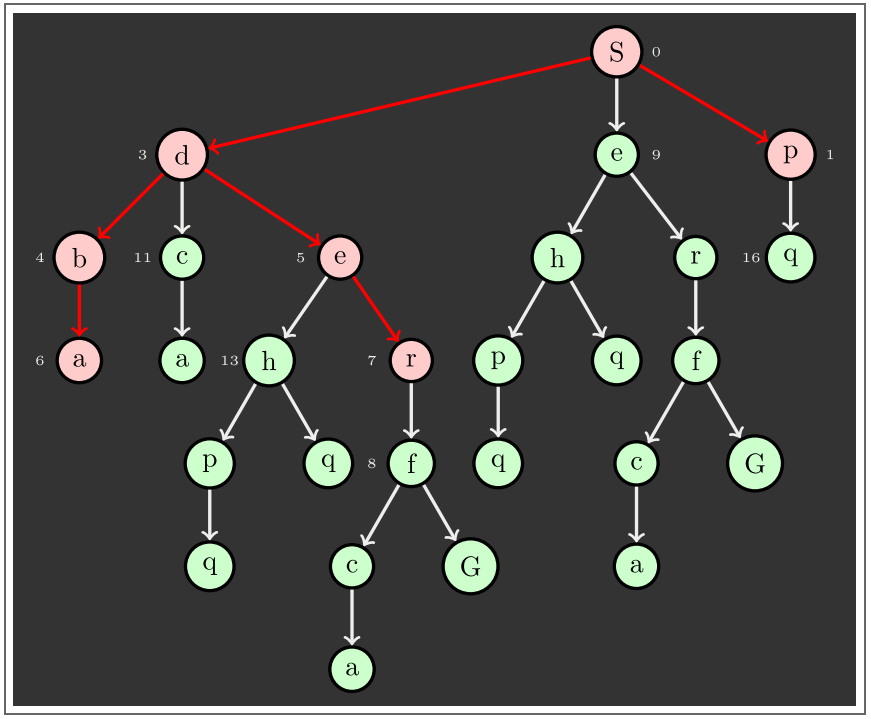
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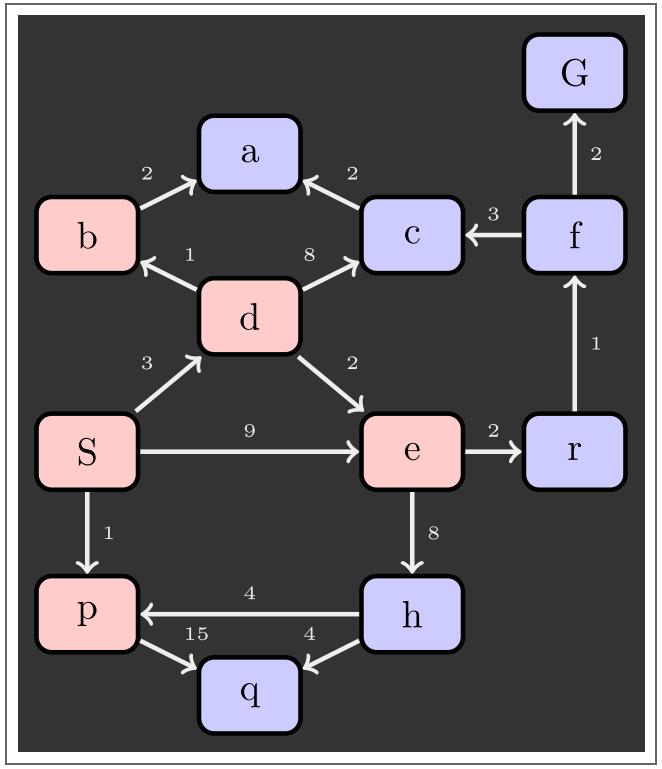
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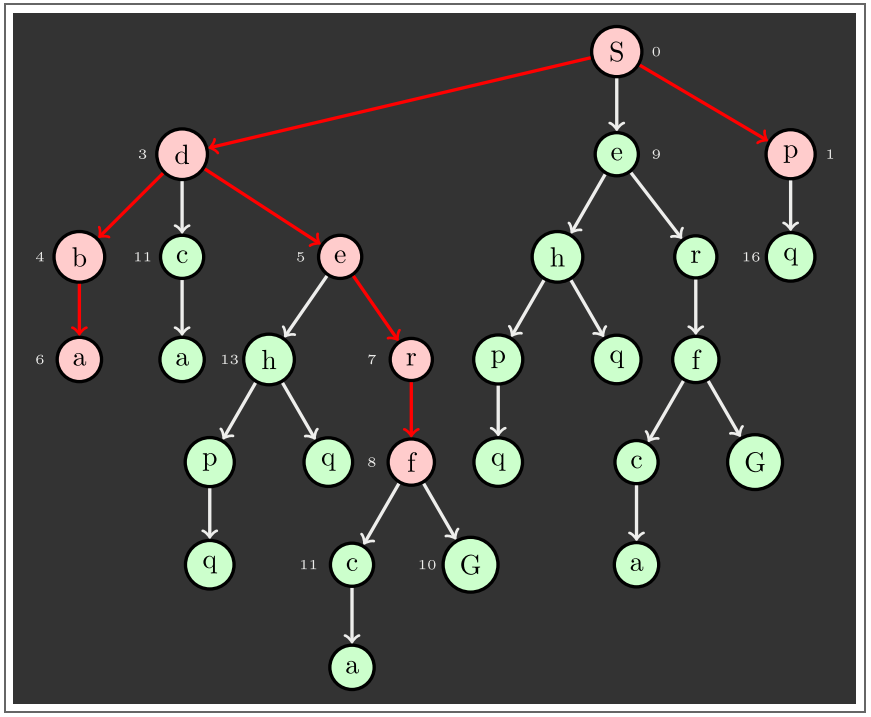
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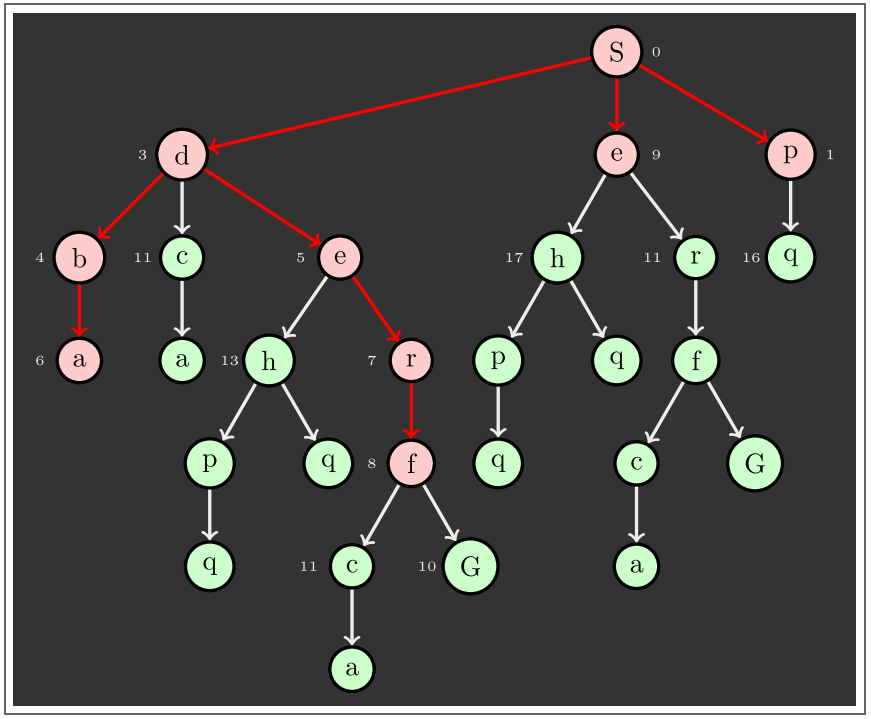
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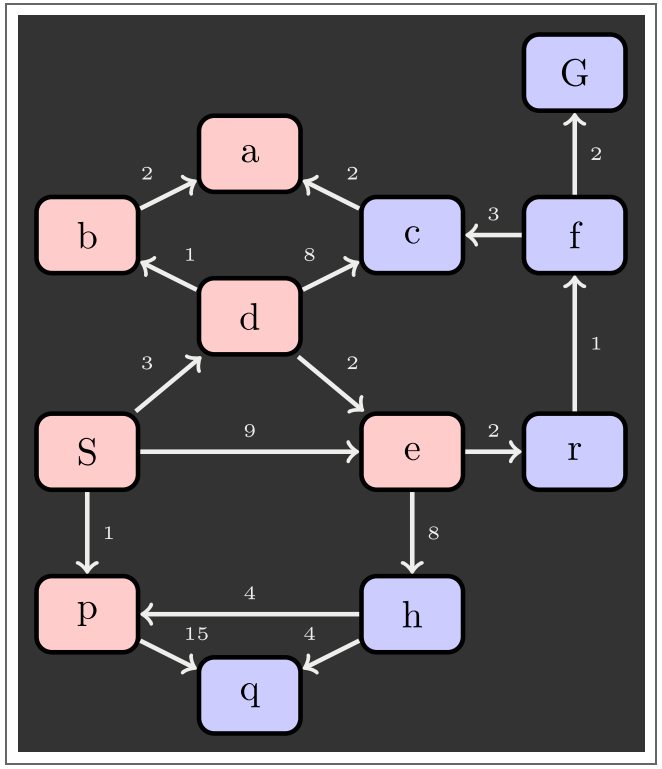
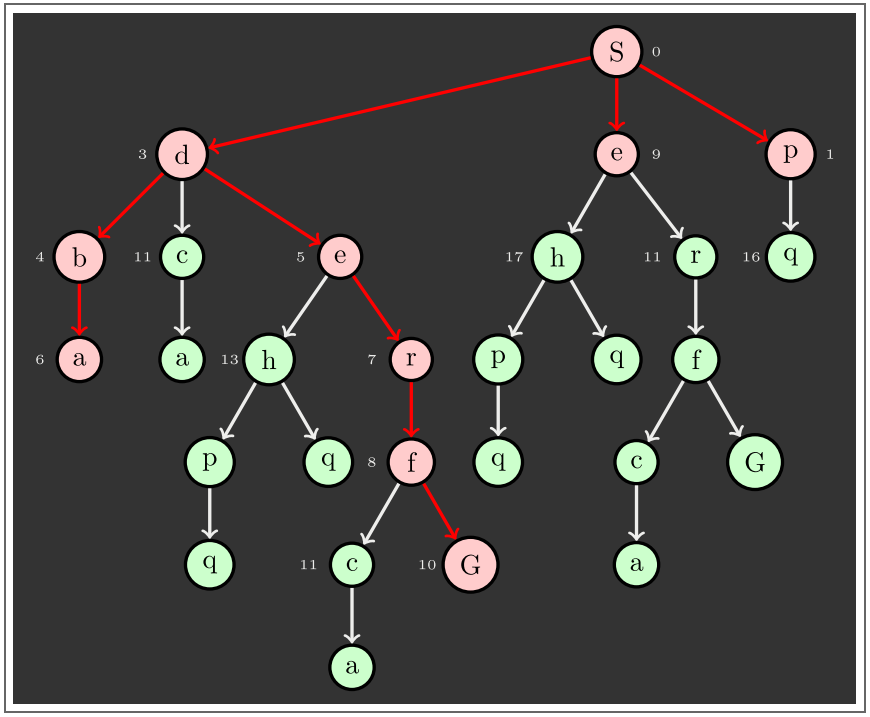
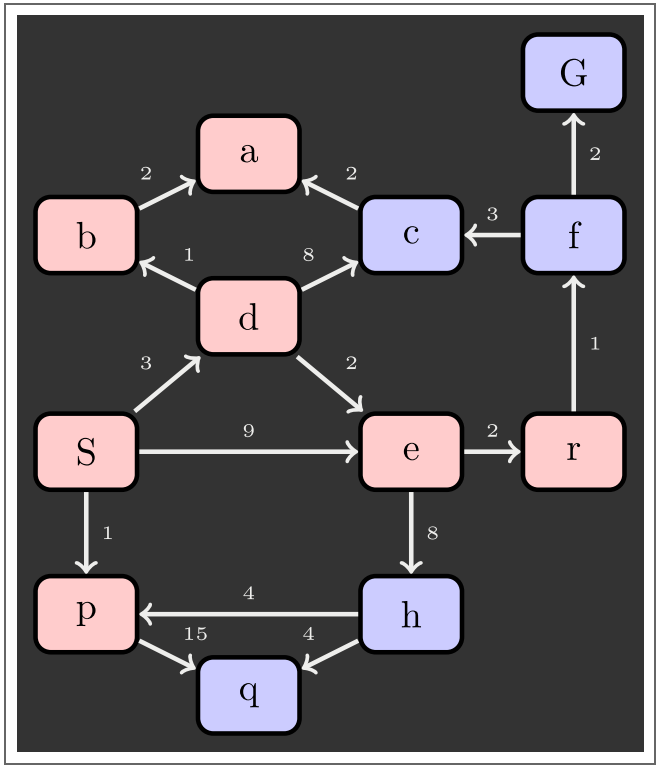




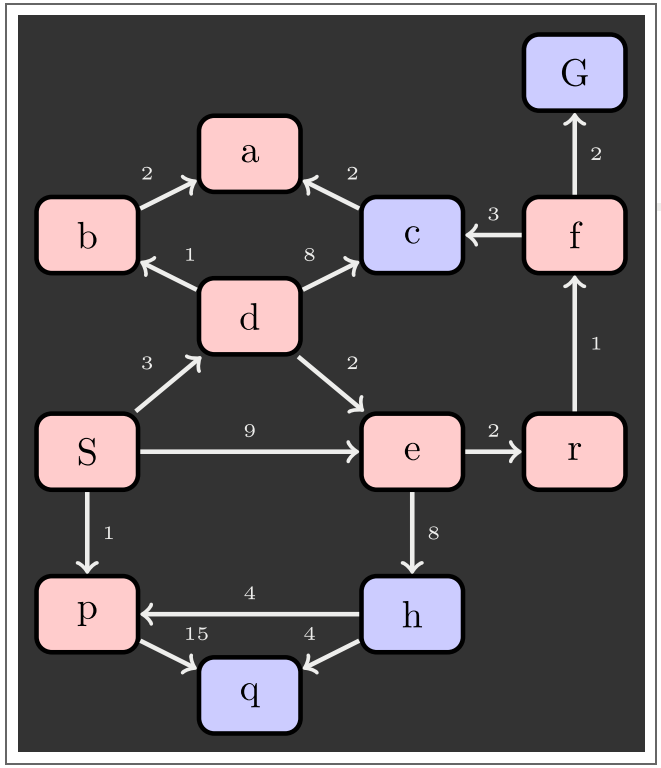
UCS PROPERTIES

What nodes UCS expand?

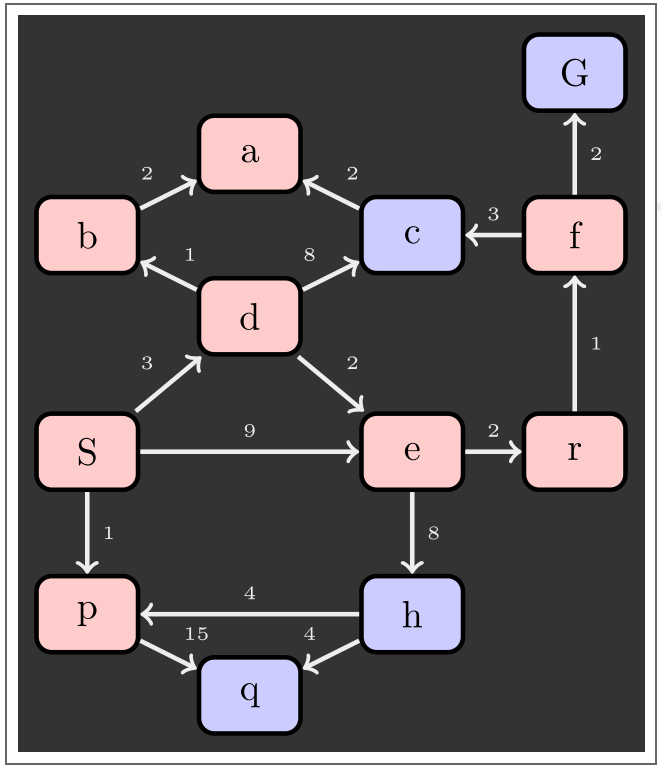
- Processes all nodes with cost less than cheapest solution!
- If that solution costs C^* and arcs cost at least ϵ, then the "effective depth" is roughly $\left(\frac{C^*}{\epsilon}\right)$



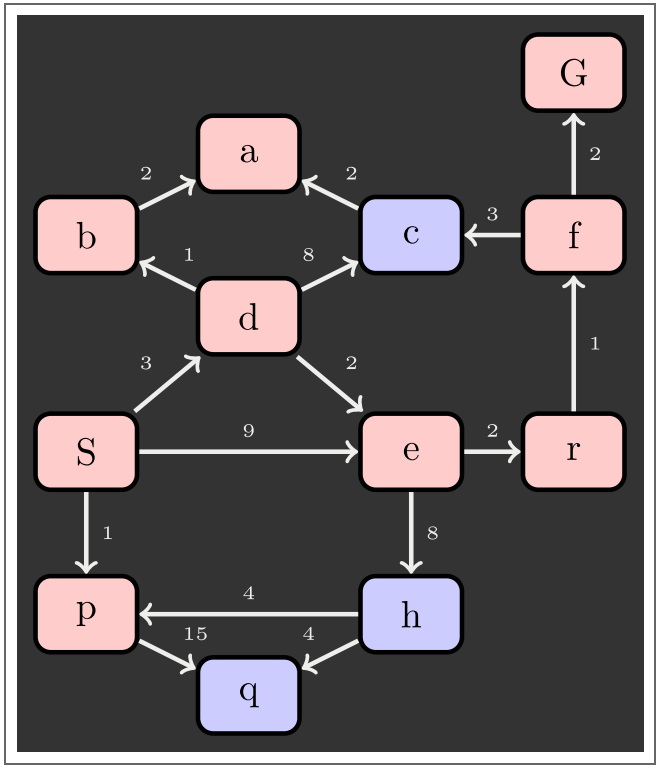
- Takes time $\mathcal{O}\left(b^{\frac{C^*}{\epsilon}}\right)$ (exponential in effective depth)



UNIFORM COST ISSUES



UCS DEMO

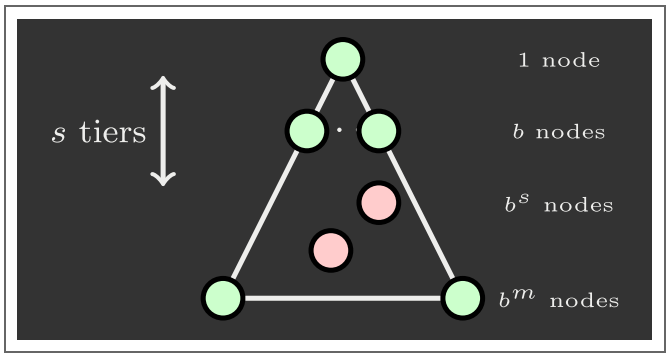


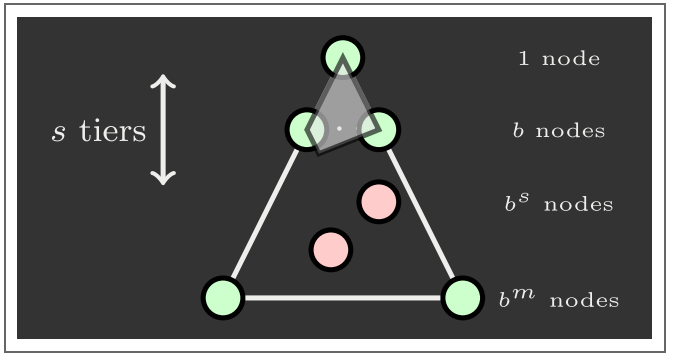
Strategy: expand a cheapest node first

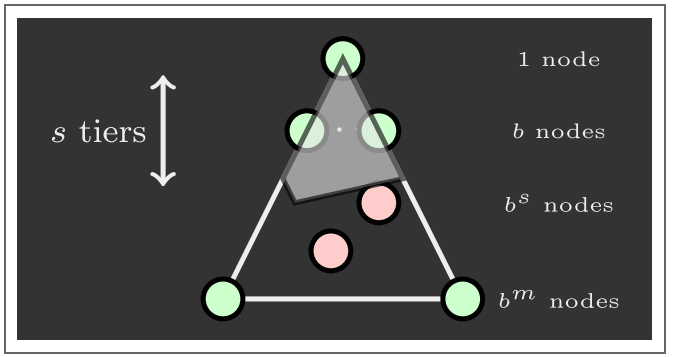
Implementation: fringe is a priority queue (priority: cumulative cost)

How much space does the fringe take?

- Has roughly the last tier, so $\mathcal{O}\left(b^{\frac{C^*}{\epsilon}}\right)$



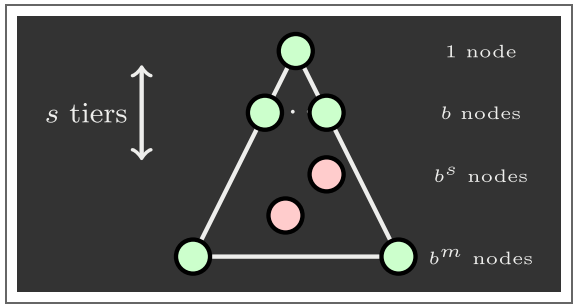




Is it complete?

- Assuming best solution has a finite cost and minimum arc cost is positive, yes!

Remember: UCS explores increasing cost contours



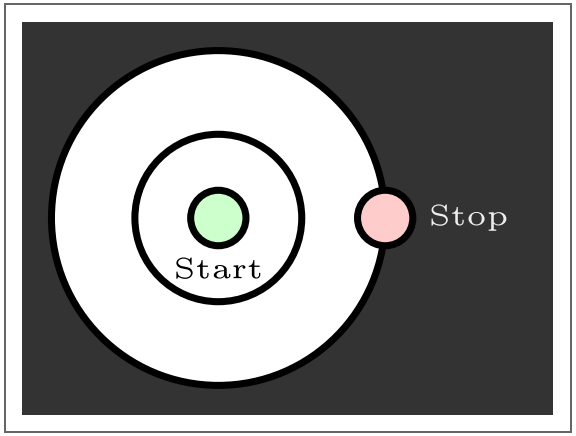
The good: UCS is complete and optimal!

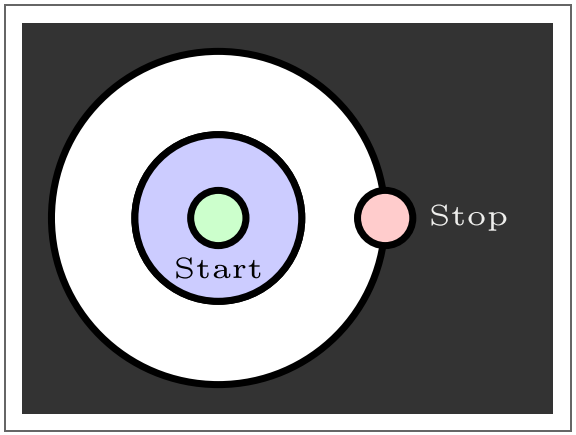
The bad:

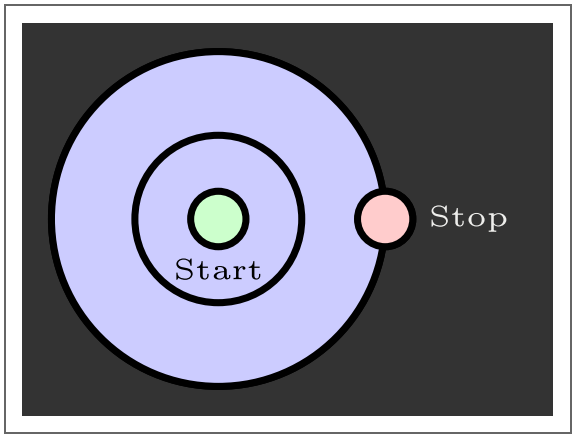
- Explores options in every "direction"

- No information about goal location

  Will be addressed soon.





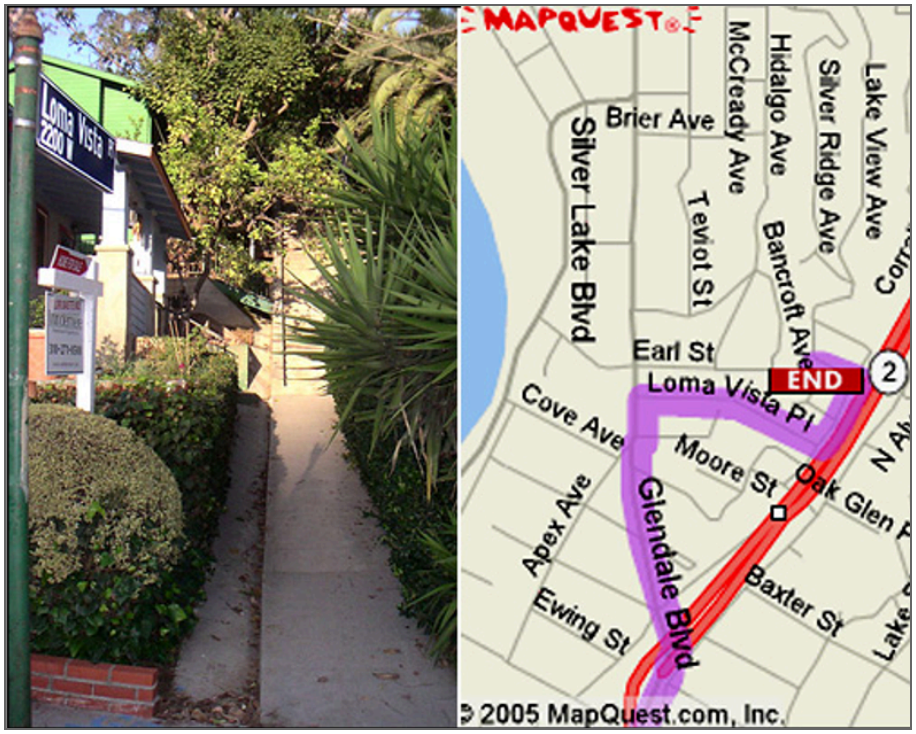


SEARCH AND MODELS

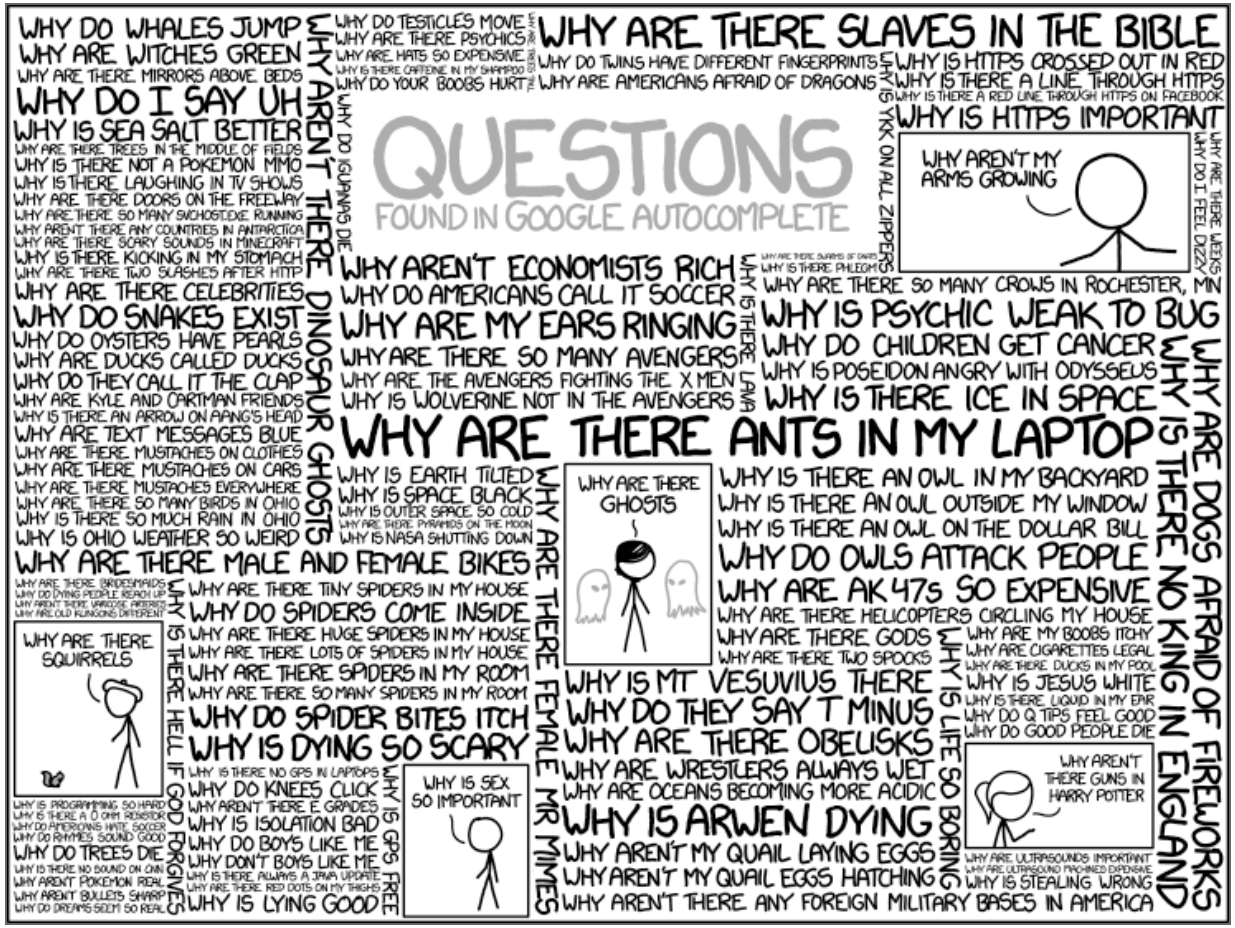
Search operates over models of the world

- The agent does not actually try all the plans out in the real world.
- Planning is all "in simulation"
- Your search is only as good as your models

SEARCH GONE WRONG?



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 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 KUNGONS DIFFERENT
WHY ARE THERE SQUIRRELS
WHY IS PROGRAMMING SO HARD
WHY IS THERE A 0 OHM RESISTOR
WHY DO APERONYMS HATE SOCCER
WHY DO RHYMES SOUND GOOD
WHY DO TREES DIE
WHY IS THERE NO BOUND ON OHM
WHY AREN'T POKEMON REAL
WHY AREN'T BULLETS SHARP
WHY DO DREAMS SEEM SO REAL
WHY AREN'T THERE DINOSAUR GHOSTS
WHY IS THERE HELL IF GOD FORGIVES
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 DO IGUANAS DIE
WHY ARE THERE SLAVES IN THE BIBLE
WHY DO TWINS HAVE DIFFERENT FINGERPRINTS
WHY ARE AMERICANS AFRAID OF DRAGONS
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 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 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 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 SEX SO IMPORTANT
WHY IS GPS FREE
WHY ARE THERE FEMALE MR MIMES
WHY ARE THERE GHOSTS
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 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 ARE THERE SWARMS OF GNATS
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 IS THERE LAVA
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 AK 47s SO EXPENSIVE
WHY ARE THERE HELICOPTERS CIRCLING MY HOUSE
WHY ARE THERE GODS
WHY ARE THERE TWO SPOOKS
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 IMAGINED EXPENSE
WHY IS STEALING WRONG
WHY ARE DOGS AFRAID OF FIREWORKS
WHY IS THERE NO KING IN ENGLAND
WHY AREN'T THERE WEEKS
WHY DO I FEEL DIZZY
WHY IS YKK ON ALL ZIPPERS

XKCD

Speaker notes