6.172
Performance
Engineering
of Software
Systems

LECTURE 19
Leiserchess Codewalk

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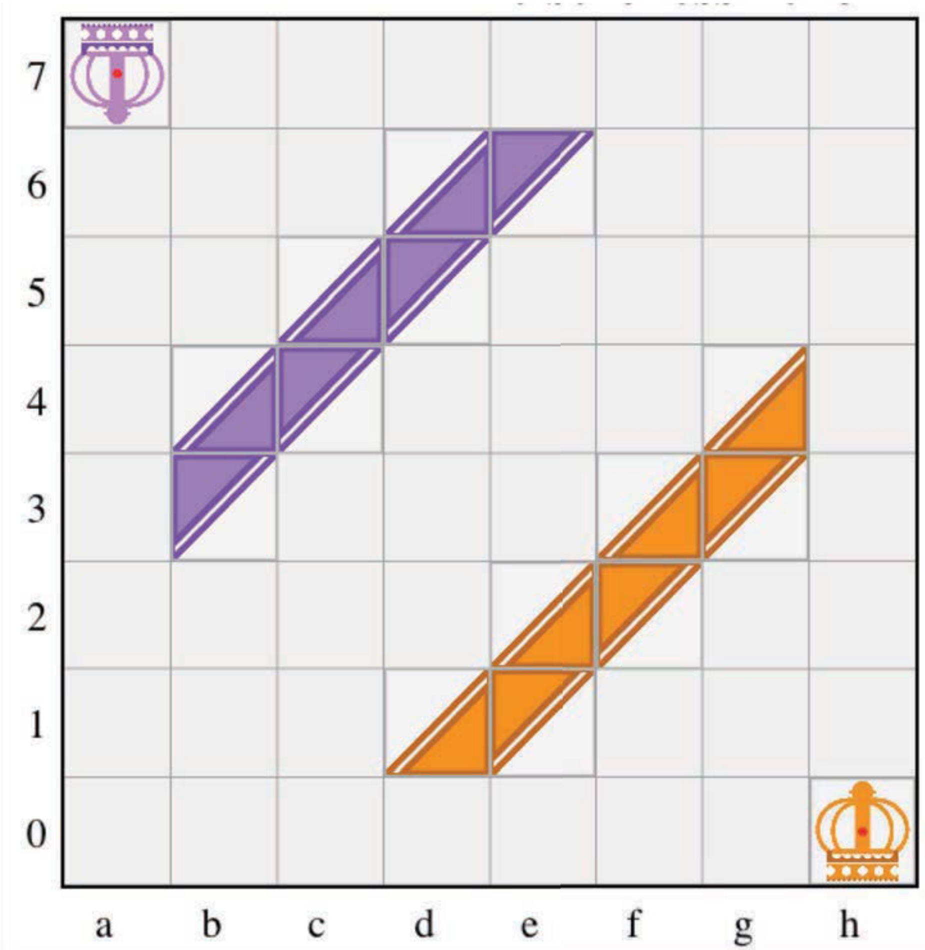
November 15, 2018

Game Rules

Leiserchess Board Game

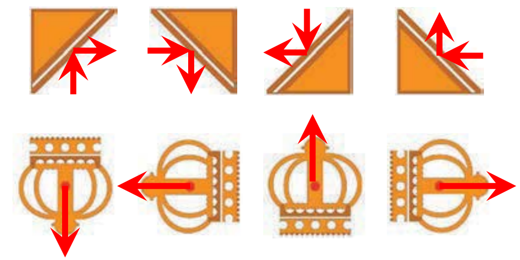


Two players: Tangerine & Lavender

Each player has 7 Pawns and 1 King

Pawn

4 Orientations



King

General Gameplay

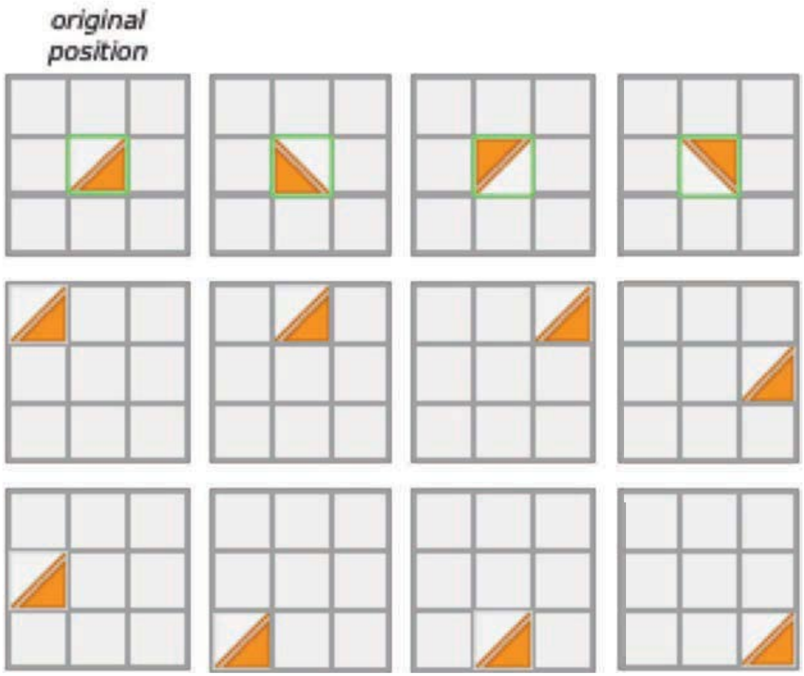
- Tangerine moves first, then play alternates between the two players.
- All pieces move the same (King or Pawn)
- Each turn has two parts: moving and firing the laser.
- The laser reflects off the long edge of the pawns and kills a pawn if it hits the other sides.
- One side wins when its King shoots the other King with its laser.

How to Move

- At the beginning of each turn, the player on move chooses a piece to move.
- There are two types of moves: ***basic*** and ***swap***.

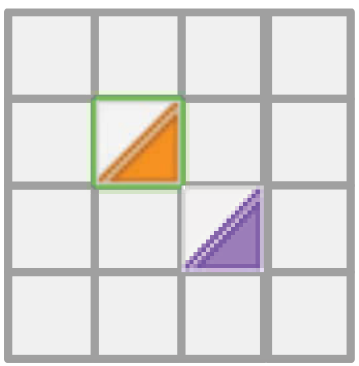
Basic Moves

- On a *basic* move, a piece can either:
  - rotate 90, 180, or 270 degrees
  - move to an empty adjacent square in any of the eight compass directions while maintaining orientation.
- A piece cannot both rotate and move.

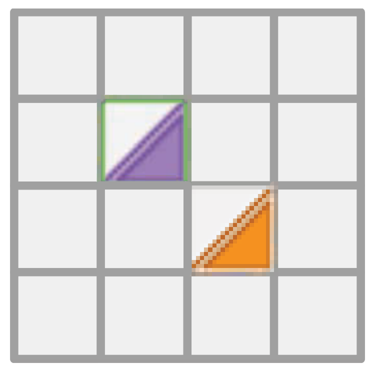


Swap Moves

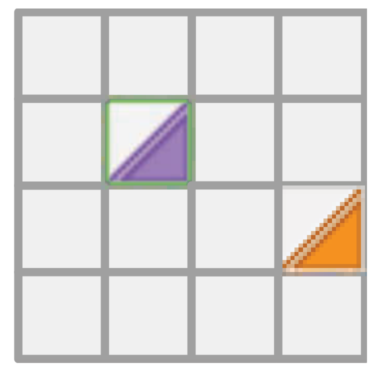
If an enemy piece occupies an adjacent square to the player's piece, the two pieces swap squares (maintaining their orientation) and the player's piece must make an extra basic move.



Initial position with Tangerine to move.



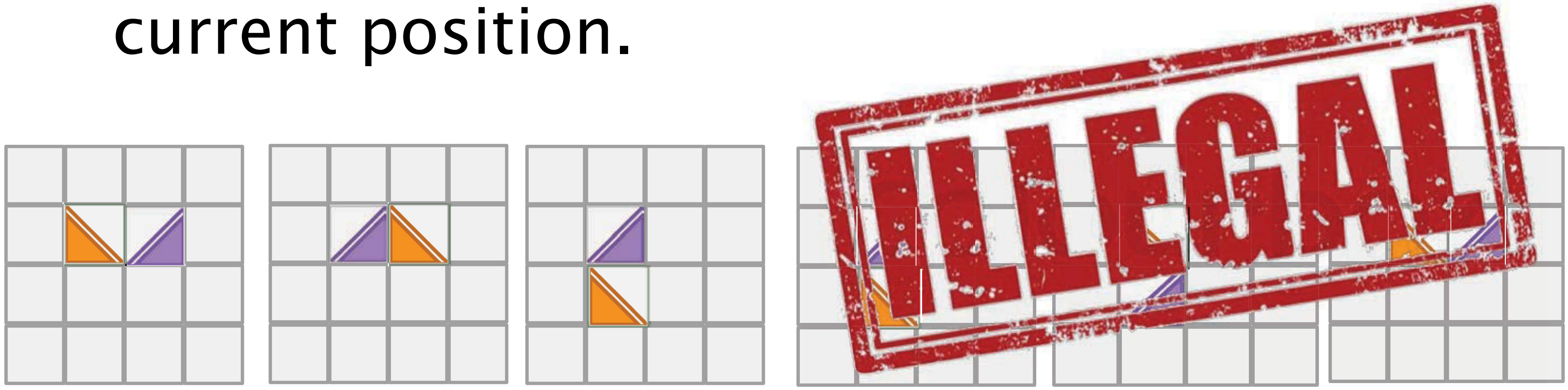
Intermediate position after swap.



Final position after extra basic move.

Ko Rule

- A Ko rule (familiar from the game of Go) helps to ensure that the game makes progress.
- A move is illegal if it "undoes" the opponent's most recent move by returning to the position immediately prior to the current position.



Tangerine performs a swap move.

Lavender performs a swap move to undo Tangerine's move.

Draws

- A draw occurs if:
  - There have been 50 moves by each side without a Pawn being zapped,
  - The same position repeats itself with the same side on move, or
  - The two players agree to a draw.

Time Control

- A chess clock limits the amount of time players have to make a move.
- When it's your move, your clock counts down.
- When it's your opponent's move, your clock stops.
- We shall use Fischer time control, which specifies an initial time budget and a time increment.

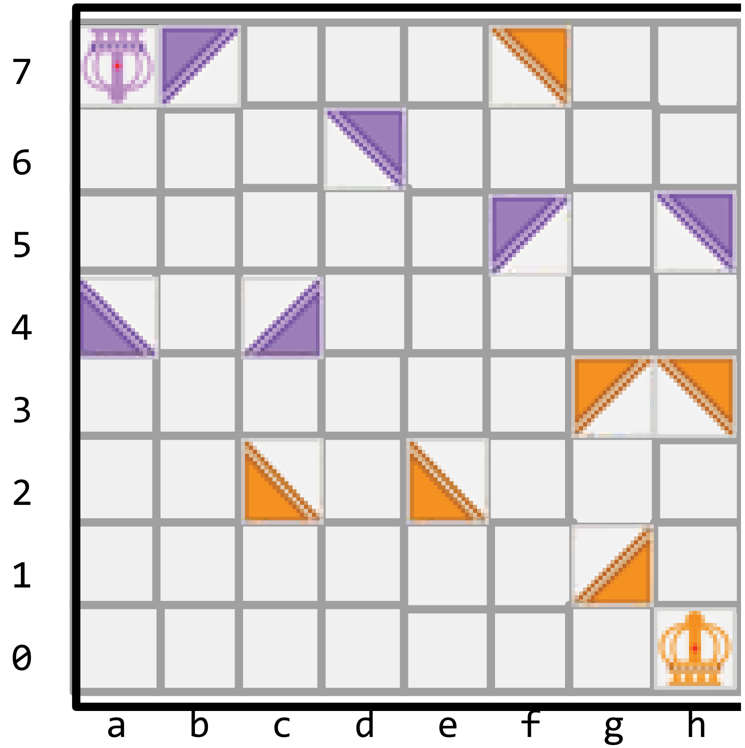
Bobby Fischer

- The notation `fis 60 0.5` means each player is allocated a time budget of 60 seconds to begin, and 0.5 seconds is added to the budget each time the player makes a move.

https://en.wikipedia.org/wiki/Time_control

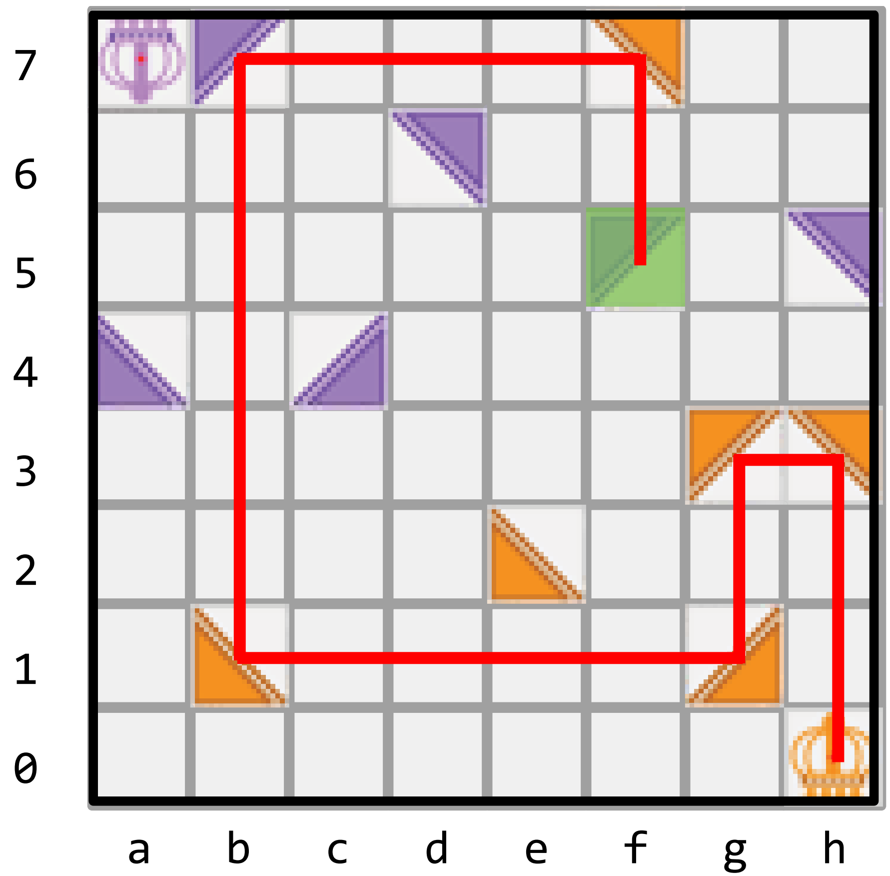
Leiserchess Tactics

- For a King to zap the enemy King, it risks opening itself up to counterattack.
- For example, how can Tangerine zap the Lavender Pawn on f5?



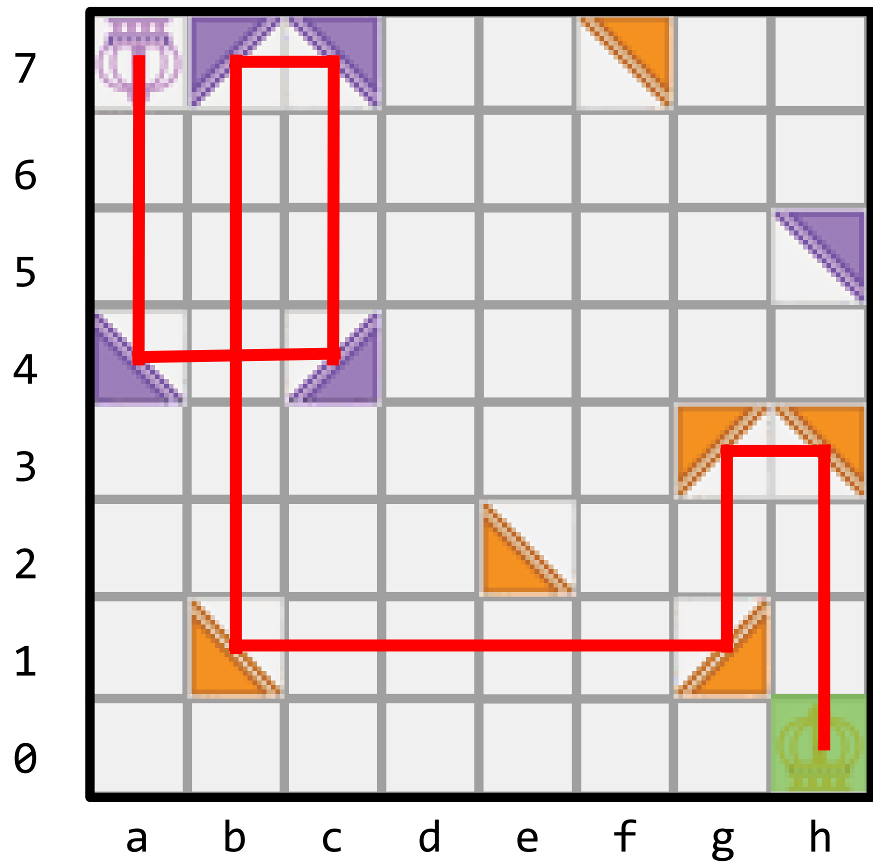
Leiserchess Tactics

Tangerine can zap Lavender's pawn on `f5` by moving its pawn on `c2` to `c1`. Now, how can Lavender counter?



Leiserchess Tactics

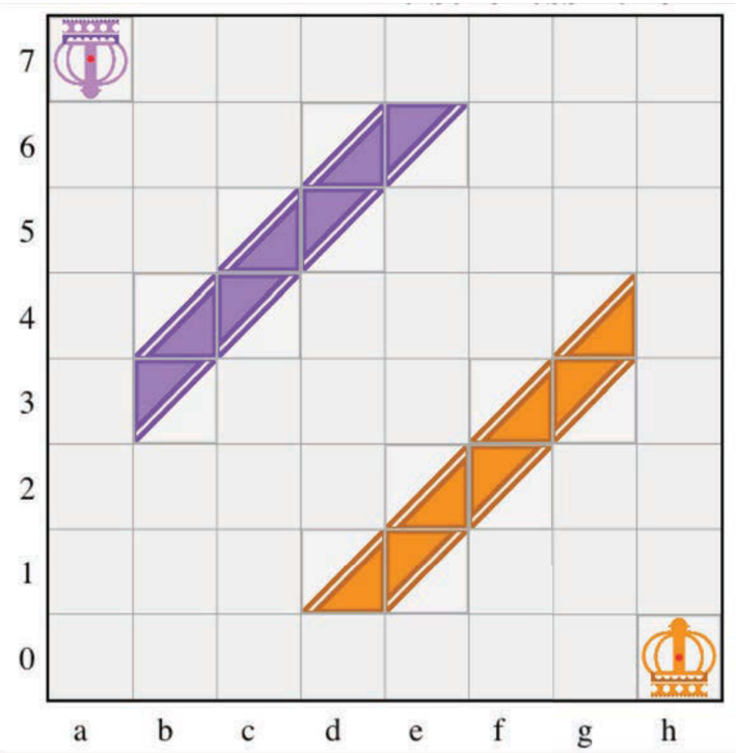
Lavender can counter by moving its pawn on d6 to c7, zapping the Tangerine King and winning the game.



Forsyth–Edwards Notation (FEN)

FEN describes a chess position using a character string (see `player/fen.c`).

David Forsyth



Example (opening position):

```
ss7/3nwse3/2nwse4/1nwse3NW1/1se3NWSE1/4NWSE2/3NWSE3/7NN W
```

https://www.chessprogramming.org/Forsyth-Edwards_Notation

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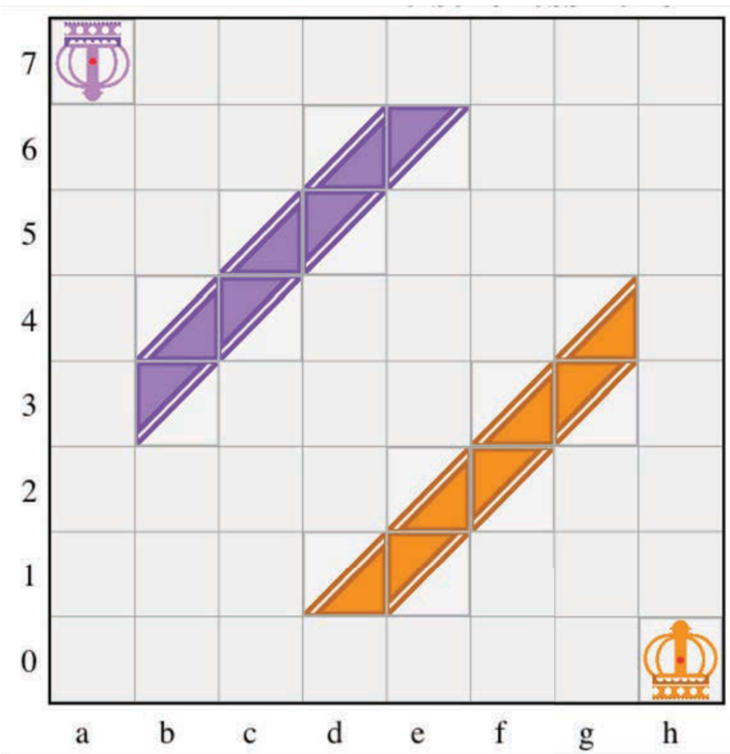

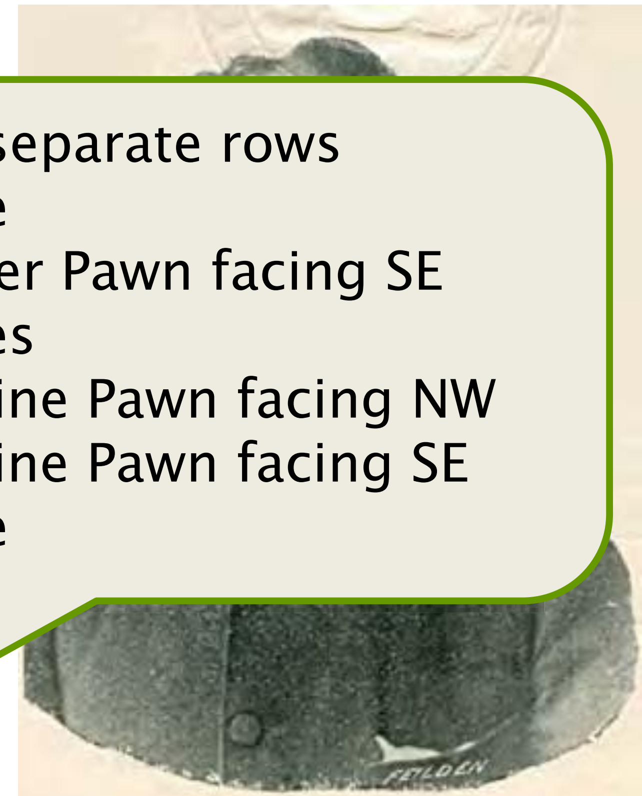

Slashes separate rows
- 1 space
- Lavender Pawn facing SE
- 3 spaces
- Tangerine Pawn facing NW
- Tangerine Pawn facing SE
- 1 space

Example (opening position):

```
ss7/3nwse3/2nwse4/1nwse3NW1/1se3NWSE1/4NWSE2/3NWSE3/7NN W
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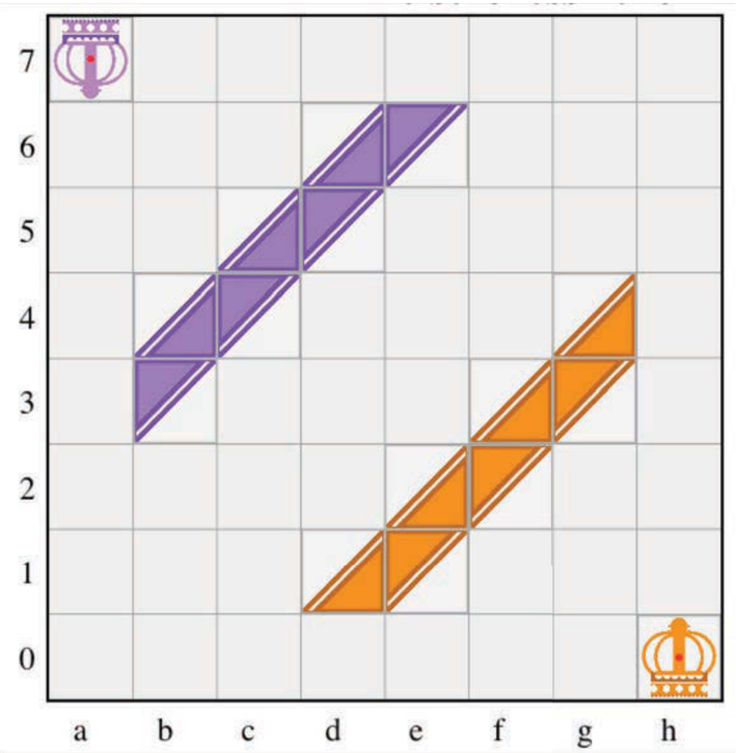


Player to move.
- W = Tangerine
- B = Lavender

Example (opening position):

`ss7/3nwse3/2nwse4/1nwse3NW1/1se3NWSE1/4NWSE2/3NWSE3/7NN W`

https://www.chessprogramming.org/Forsyth-Edwards_Notation

Algebraic Notation for Games

1.	g4g5	e6e7				…5.	e5e6	c3c2
2.	g5g4	e7e6	19.	f3		…6.	a1b1	c1L
3.	g4L	b3L	20.	e4d3c4	a7b7	37.	b1R	d0R
4.	g4h5	b4R	21.			38.	e0L	c1b2
5.	f3e4	d5e4f5	22.	h4		39.	b1b2c1	b1a1
6.	f2e3	f5g5	23.	e4		40.	c1b2	a1b2a3
7.	h5g6	g5h4	24.			…1.	e6U	a3R
8.	h0g0	c4R	25.	b5		…2.	e6d5	a7R
9.	e3e4	b3b2	26.	b4		…3.	f5e6	c2U
10.	g0f0	d6d7	27.	g5f6e5	a7L	44.	a1b1	c7U
11.	d5c5b5	h4g3f2	28.	g6		45.	e0f0	c2d2
12.	e2f2g2	c4b3	29.			46.	b1c1	c7b7
13.	e4d5R	d7L	30.	e1e0	b4c3	47.	d5L	d2e3
14.	d5e6e7	b2b1	31.	f5g6f6	b3c2	48.	f0g1	e3f3
15.	e1d0	e			…2d1c0	49.	g1h1	f3g3
16.	b5c4	c				50.	e6f5	g3h3
17.	d5R	e				0-1		

Basic move with translation

Basic move with rotation

Swap move with translation

Swap move with rotation

1–0 Tangerine wins
0–1 Lavender wins
1/2–2/1 Draw

https://en.wikipedia.org/wiki/Algebraic_notation_(chess)

Project Organization

README

Directories under `project4`:

`doc`: Leiserchess rules and documentation for the game-engine interface.

`autotester`: Java local autotester

`BayesElo`: parses Elo results from autotester.

`pgnstats`: parses statistics from autotester results.

`tests`: test specifications for the local autotester.

`player`: code for your Leiserchess bot. You will be optimizing the code in here!

`webgui`: local webgui where you can watch the game and play it.

Java Autotester

The Java local autotester is in `autotester/` under the code distribution.

You can test changes to your bot using time trials over many games.

The `tests/` directory holds configuration files for your autotests:

- number of games,
- bots in your trials,
- time control,
- etc.

Java Autotester Configuration

```
cpus = 12
book = ../tests/book.dta
game_rounds = 500
title = basic

# now we have the player definitions
# --

player = reference
invoke = ../player/leiserchess
fis = 20 0.5

player = with_change
invoke = ../player/leiserchess_with_change
fis = 20 0.5
```

Binary for bot

Modified from `tests/basic.txt`.

Universal Chess Interface (UCI)

Leiserchess uses the Universal Chess Interface (UCI), a communication protocol for automatic games to pass information between the bots and the autotester.

UCI allows the programmer (or autotester) to enter the move made by the game engine.

https://www.chessprogramming.org/UCI

Elo Ratings

The Elo rating system measures relative skill levels in zero-sum games like chess.

A player's Elo rating depends on the Elo ratings of its opponents.

Example output from autotests:

Rank	Name	Elo	+	-	games	score	oppo.	draws
1	test6	269	137	100	33	94%	-140	6%
2	test5	40	96	98	33	55%	-29	6%
3	test4	-309	113	185	34	3%	155	0%

Webgui

The local webgui lets you watch a game — or even play one — without sending it to the scrimmage server.

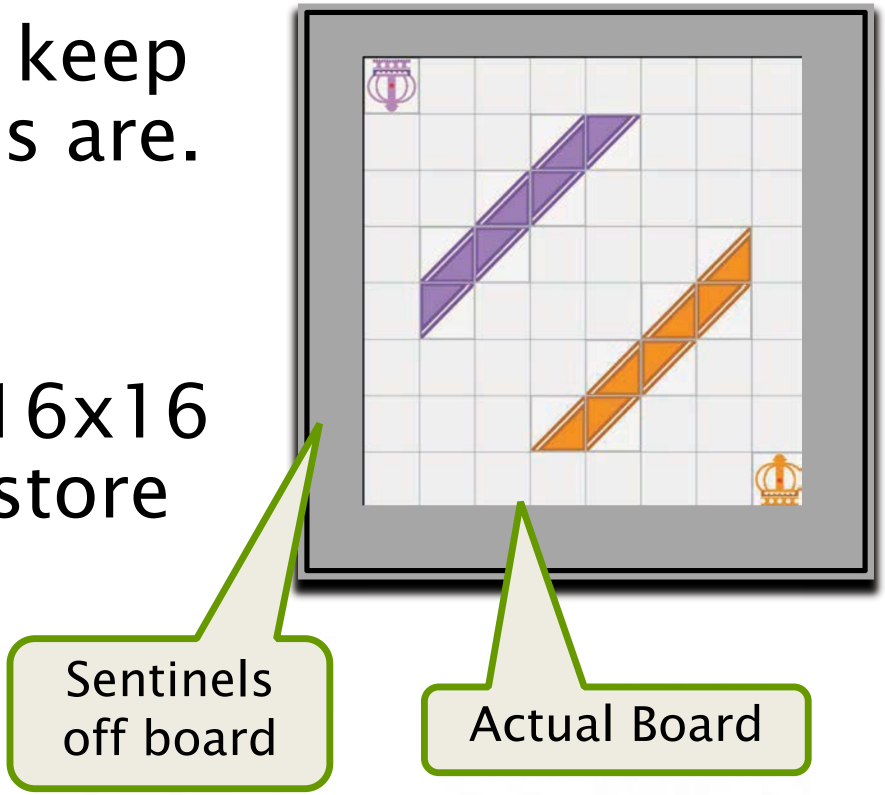
You can run it using the commands in `webgui/README`.

Move Generation
(`move_gen.c`)

Board Representation

Any chess program needs a board representation to keep track of where the pieces are.

The reference implementation uses a 16x16 board with sentinels to store an 8x8 board.



https://www.chessprogramming.org/Board_Representation
https://www.chessprogramming.org/Mailbox
https://www.chessprogramming.org/10x12_Board

Position

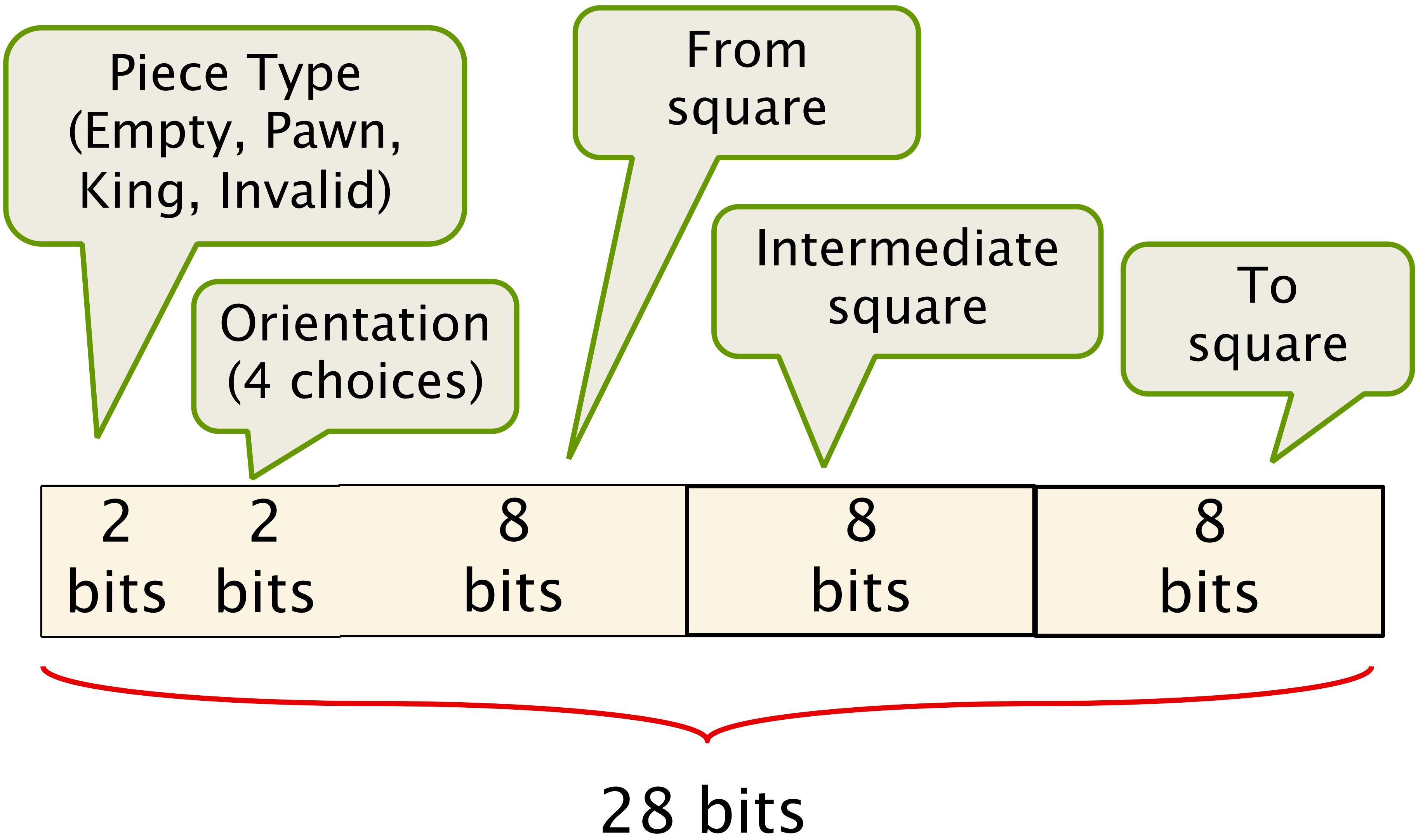
```
typedef struct position {
  piece_t          board[ARR_SIZE];
  struct position* history;     // history of position
  uint64_t         key;         // hash key
  int              ply;         // Even ply are White, odd are
Black
  move_t           last_move;   // move that led to this
position
  victims_t        victims;     // pieces destroyed by shooter
  square_t         kloc[2];     // location of kings
} position_t;

(move_gen.h:151)
```

Board representation

The position in the Leiserchess player stores the board representation, history, and other information about how we got to this point in the game.

Move Representation



Move Generation

- At each turn, our program needs to see all the moves it can possibly make.
- In `move_gen.c:286`, we generate all the moves given a position depending on whose turn it is.
- In the reference implementation, we iterate through the entire board and generate all the moves for each piece of the right color when we pass by it.

Perft

`Perft` is a debugging function that enumerates all legal moves of a certain depth (`move_gen.c:698`).

If you modify the move generator, make sure that `Perft` returns the same results.

```
uint64_t Perft(int depth)
{
    move_t move_list[256];
    int n_moves, i;
    uint64_t nodes = 0;

    if (depth == 0) return 1;

    n_moves = move_gen(move_list);
    for (i = 0; i < n_moves; i++) {
        make_move(move_list[i]);
        nodes += Perft(depth - 1);
        unmake_move(move_list[i]);
    }
    return nodes;
}
```

https://www.chessprogramming.org/Perft

Move Ordering

Move Ordering in Search

Alpha-beta and principal variation search depend on putting the best moves at the front to trigger an early cutoff.

How do we determine which moves are best without static evaluation at every level?

We call `get_sortable_move_list` at `search.c:144` and implement it at `search_common.c:402`.

Move Representation

Moves are represented in 28 bits (`int32_t`). If we want to make them sortable, we use 64 bits (`int64_t`) and use the upper 32 as the sort key.

The move representation is defined in `move_gen.h:119`.

STATIC EVALUATION
(eval.c)

Static Evaluation

We use static evaluation to determine which positions are better than others (and therefore which moves we should make).

The function `eval(position_t* p)`, located at `eval.c:438`, generates a score given a position based on heuristics (higher means better).

At first, we suggest focusing on optimizing the existing structs and evaluation heuristics before coming up with new ones.

King Heuristics

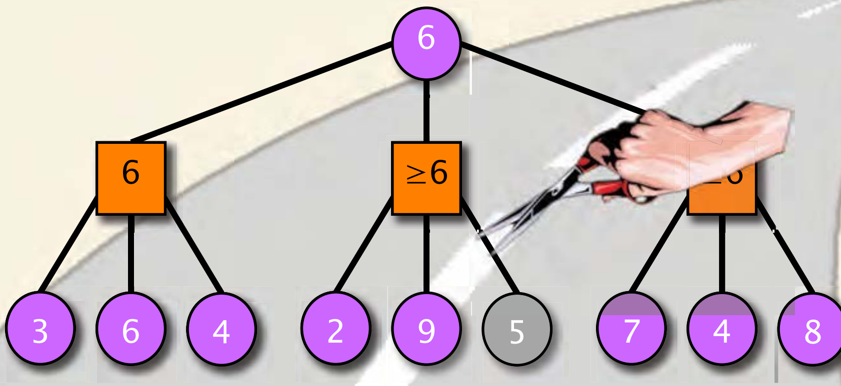
- `KFACE`: bonus for your King facing the enemy king.
- `KAGGRESSIVE`: bonus for the King with more space behind it (to the end of the board)
- `MOBILITY`: how many spaces around your King are free.

Pawn Heuristics

- `PCENTRAL`: bonus for Pawns near the center of the board.
- `PBETWEEN`: bonus for Pawns between the two Kings.

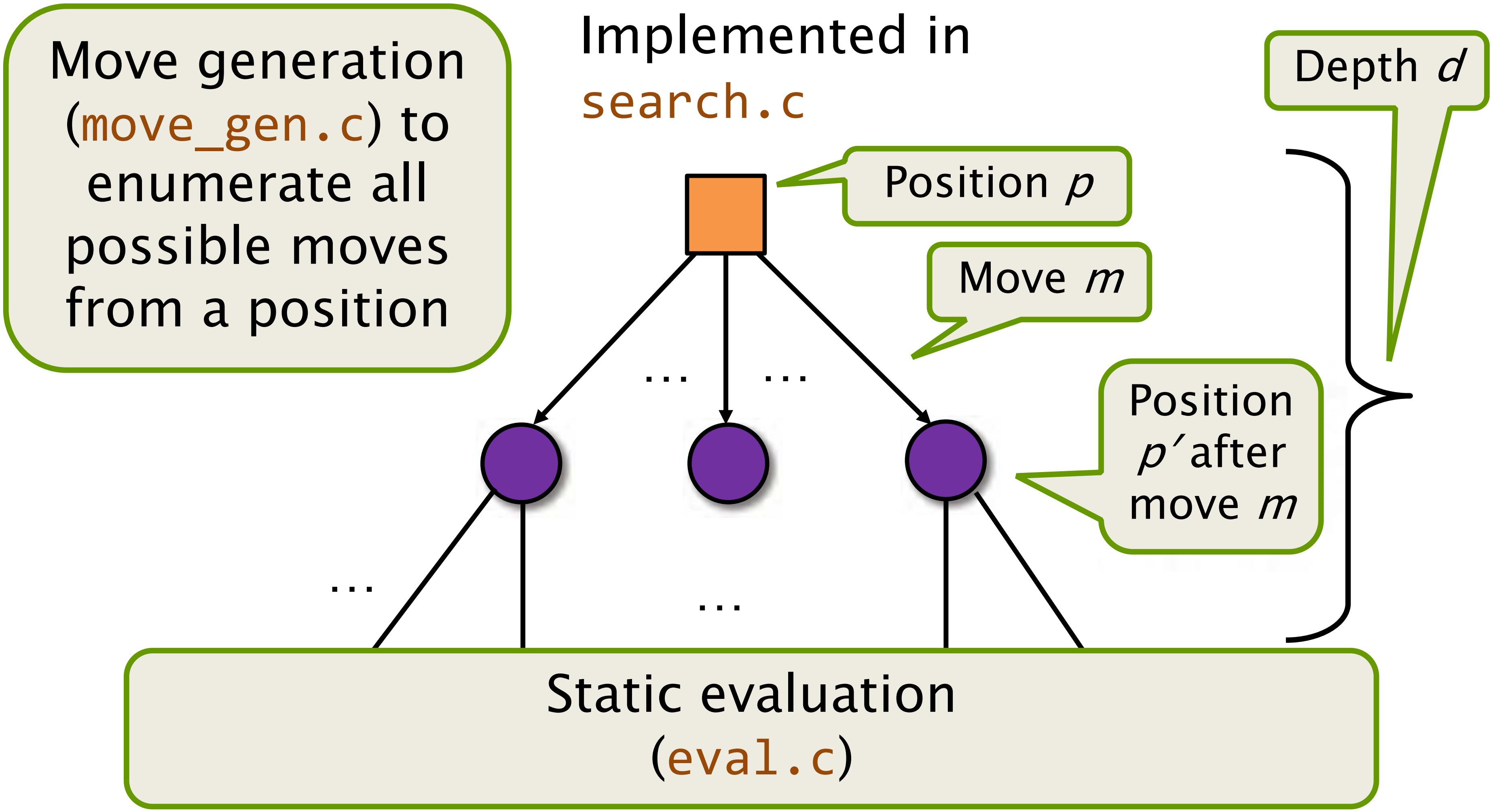
Distance Heuristics

LCOVERAGE: measures how much the board near the enemy king is covered by lasers after making all possible moves from a position.



ALGORITHMS FOR GAME-TREE SEARCH

Game Search Trees

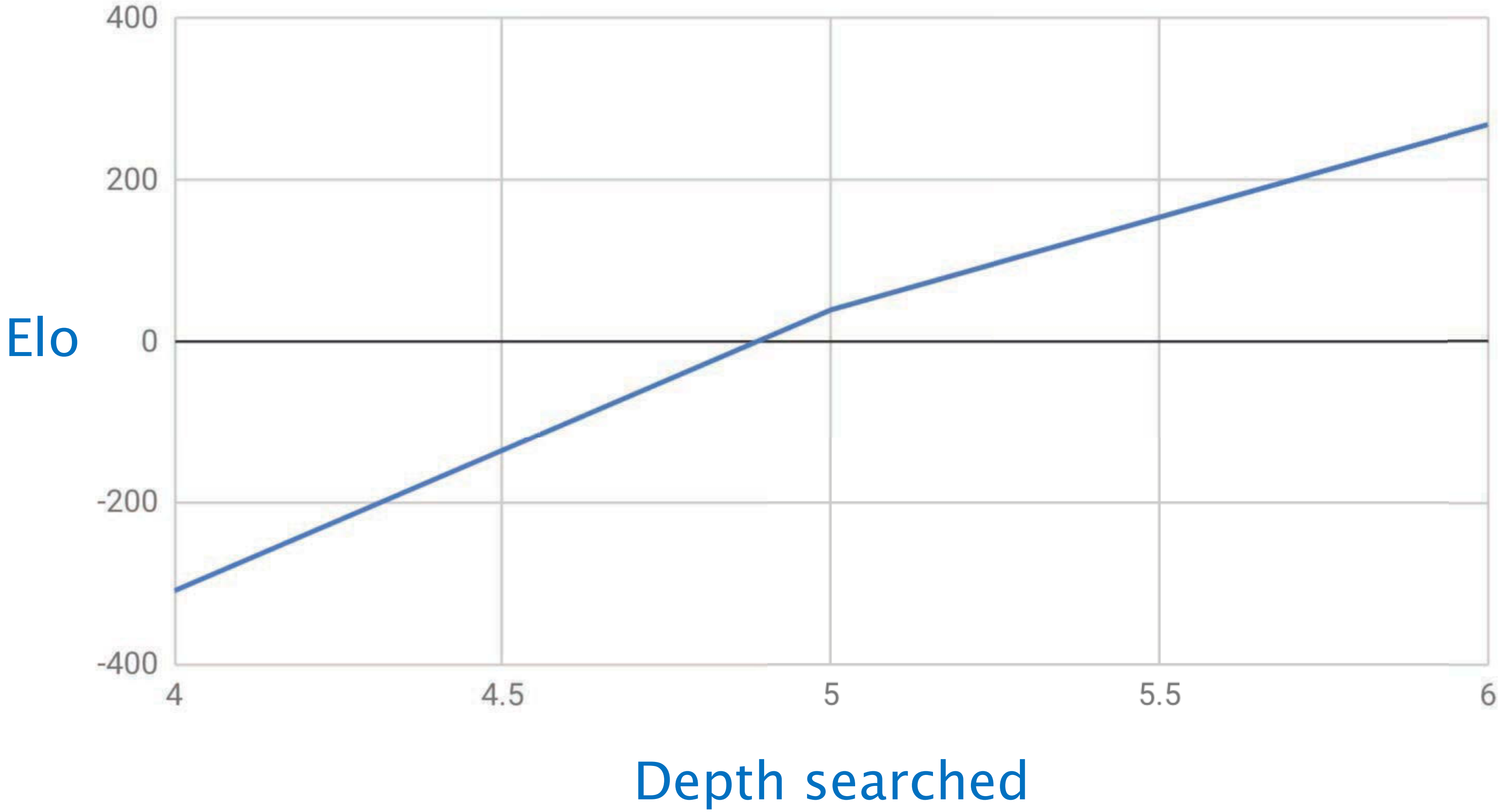


Quiescence Search

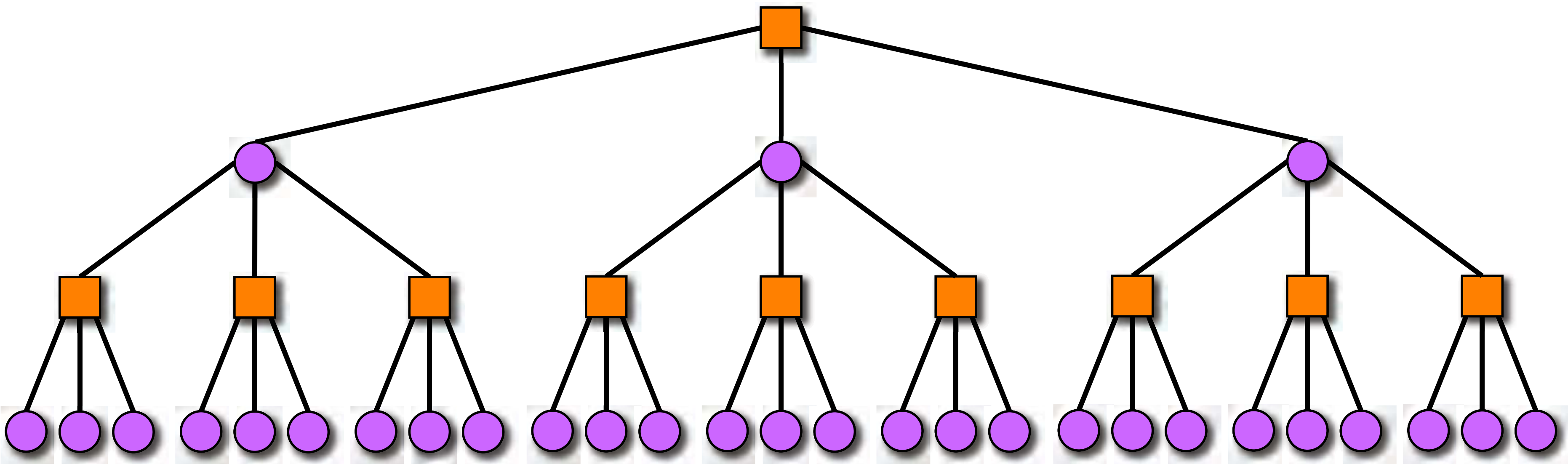
- Evaluating at a fixed depth can leave a board position in the middle of a capture exchange.
- At a "leaf" node, continue the search using only captures — quiet the position.
- Each side has the option of "standing pat."
- Implemented at `search_common:182`.

https://www.chessprogramming.org/Quiescence_Search#Standing_Pat

Higher Depth Search = Better AI



Min-Max Search

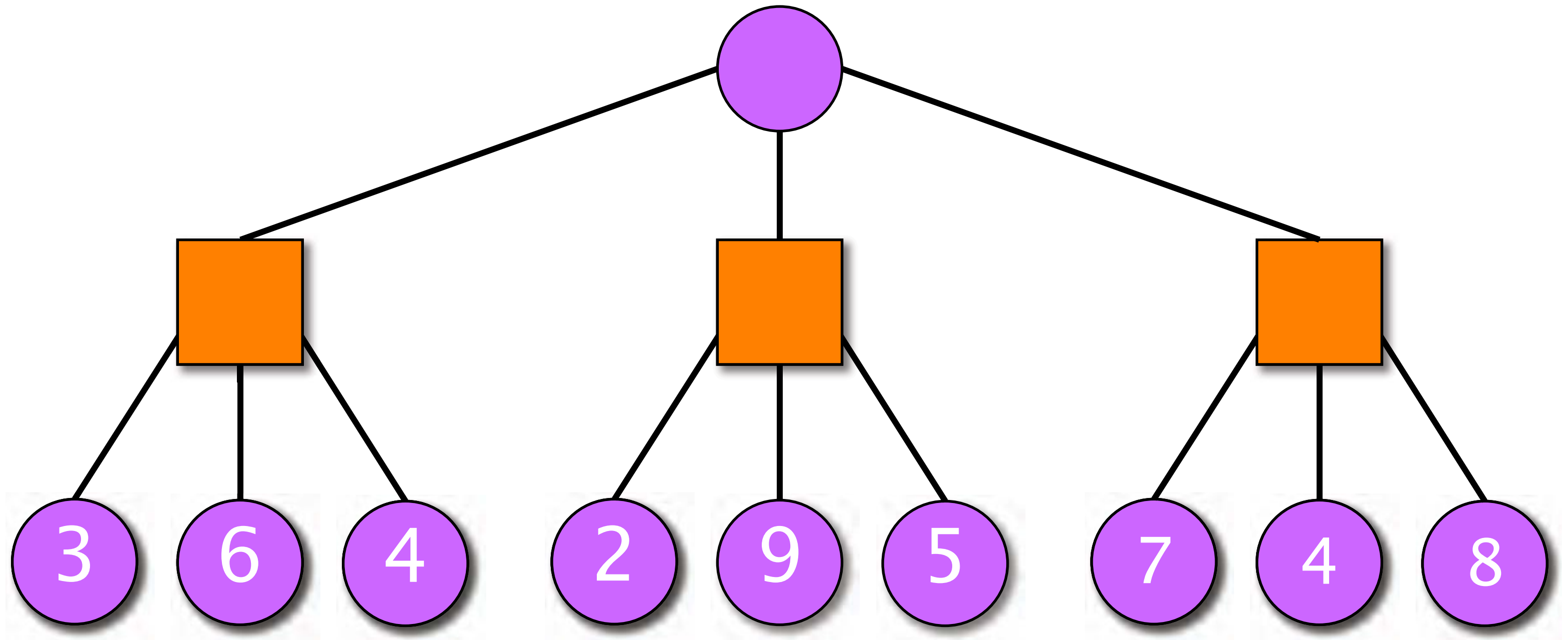


- Two players: MAX ■ and MIN ●.
- The game tree represents all moves from the current position within a given search ply (depth).
- At leaves, apply a static evaluation function.
- MAX chooses the maximum score among its children.
- MIN chooses the minimum score among its children.

Alpha-Beta Strategy

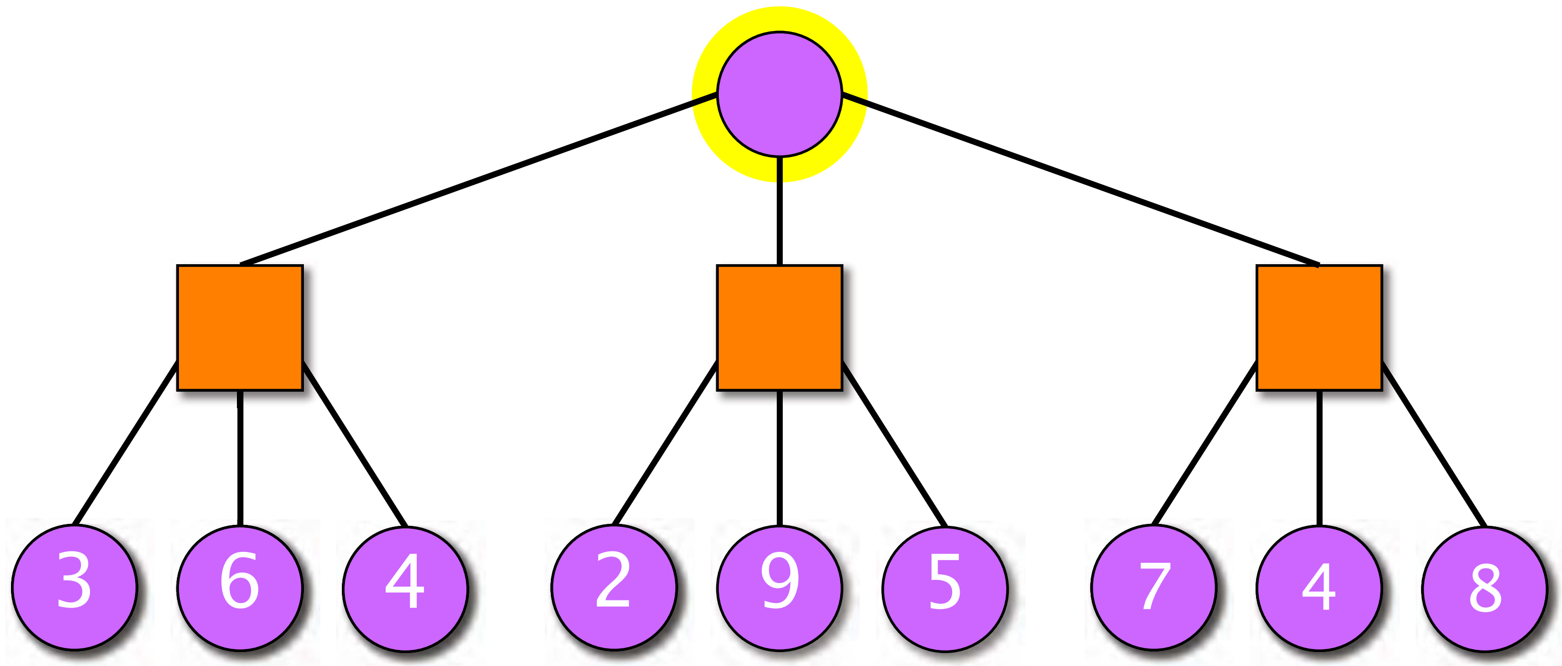
- Each search from a node employs a window `[alpha, beta]`.
- If the value of the search falls below `alpha`, keep searching.
- If the value of the search falls between `alpha` and `beta`, then increase alpha and keep searching.
- If the value of the search falls above `beta`, generate a beta cutoff and return.

Alpha-Beta Pruning



IDEA: If MAX discovers a move so good that MIN would never allow that position, MAX's other children need not be searched — beta cutoff.

Alpha-Beta Pruning



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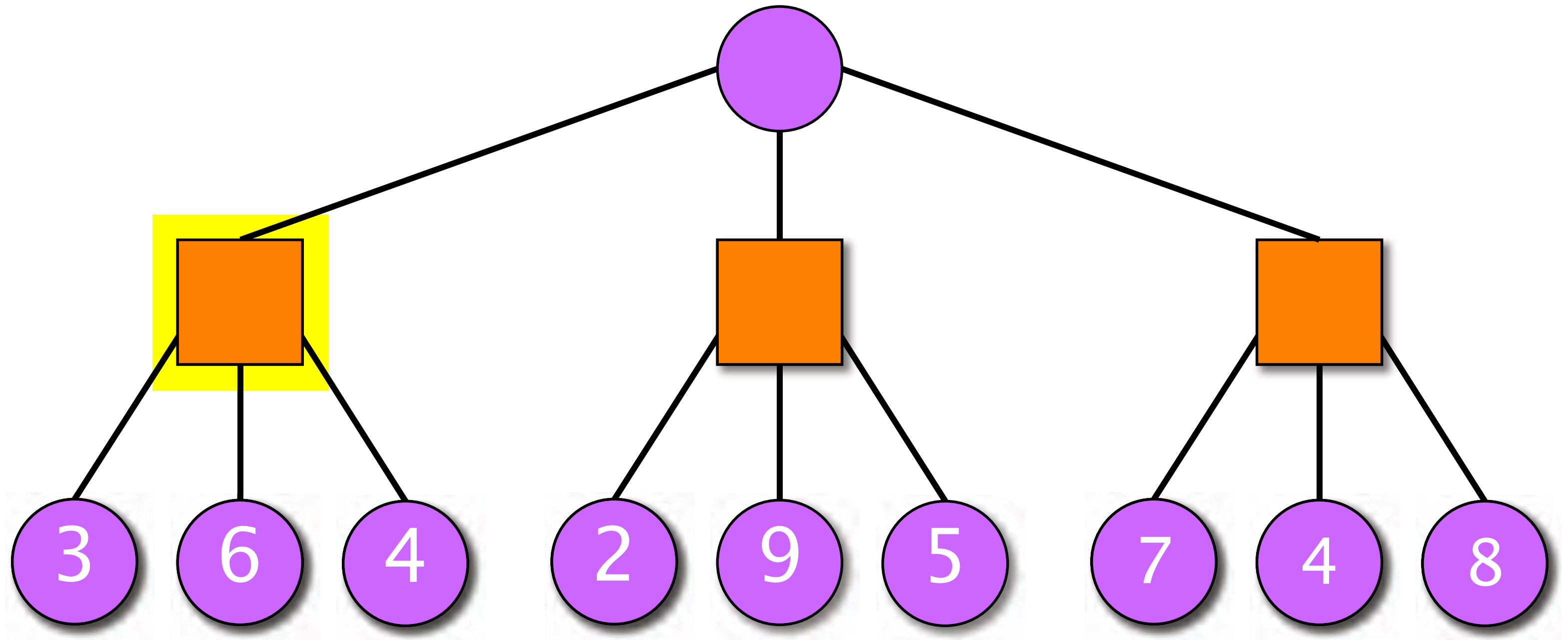

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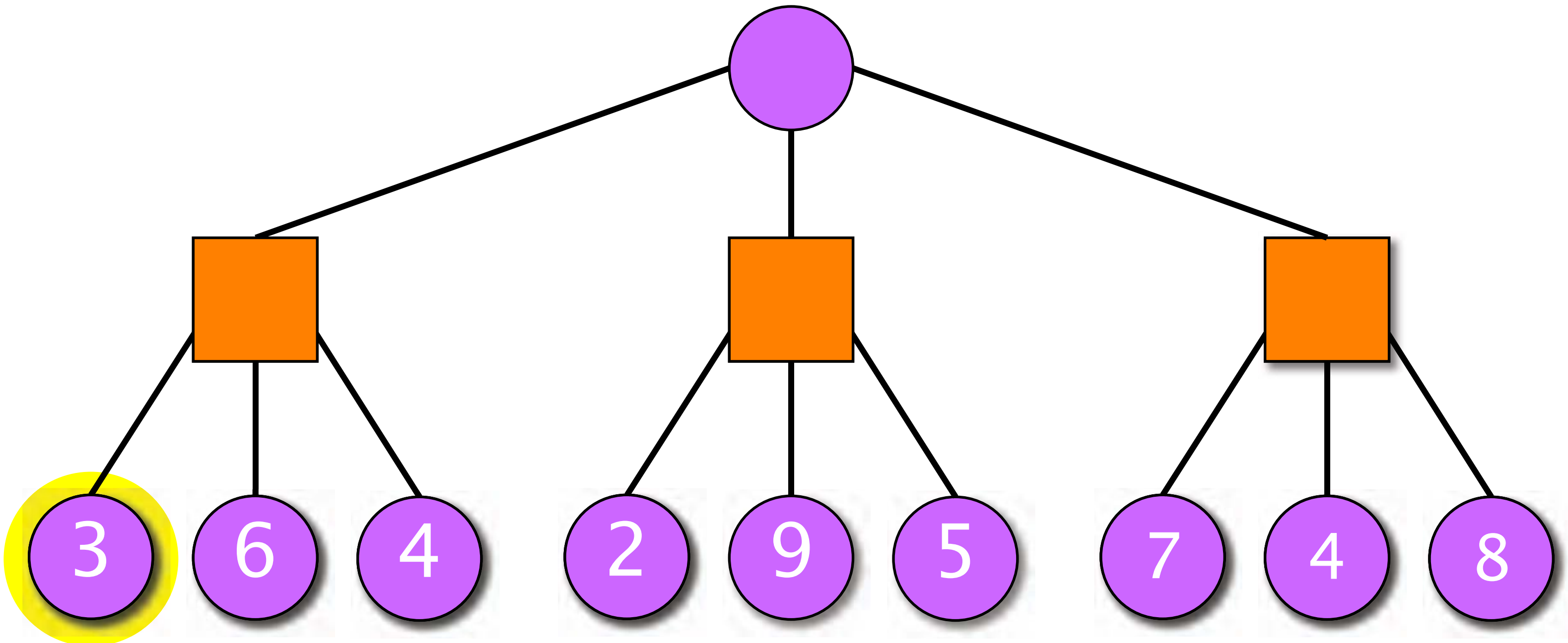

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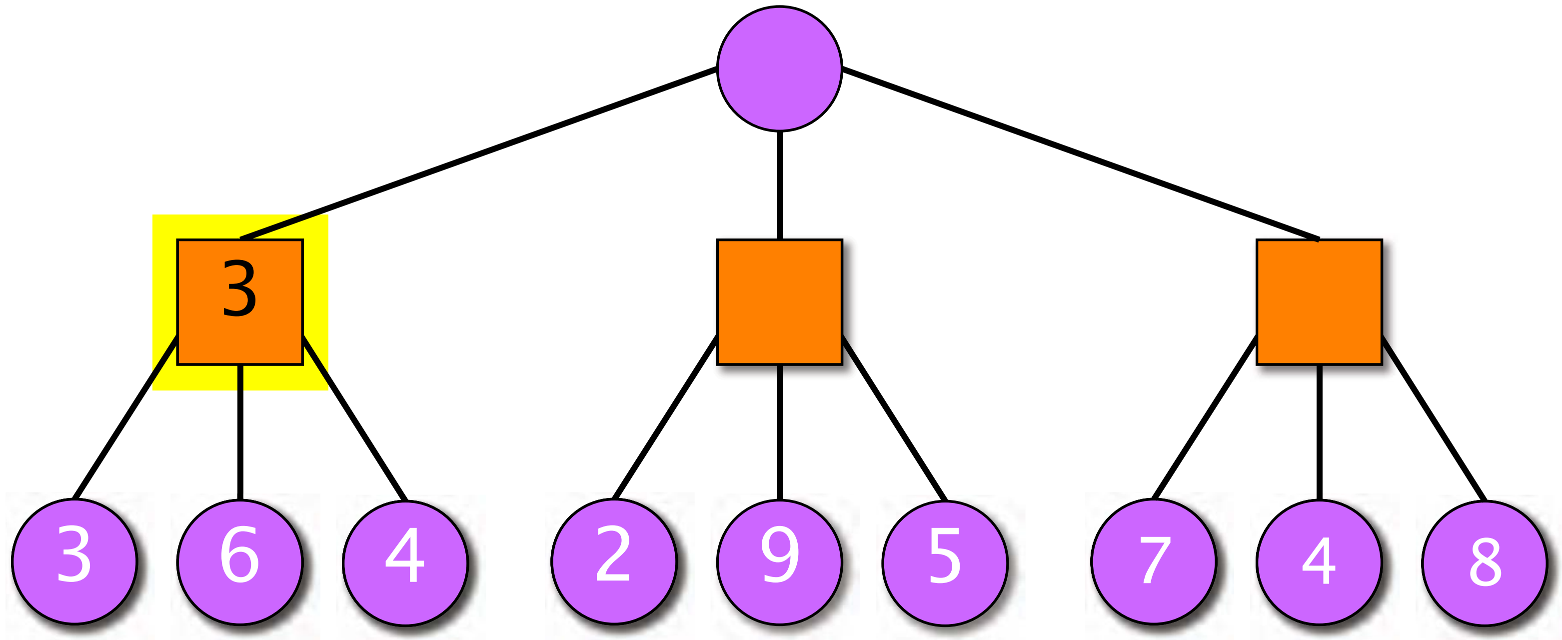

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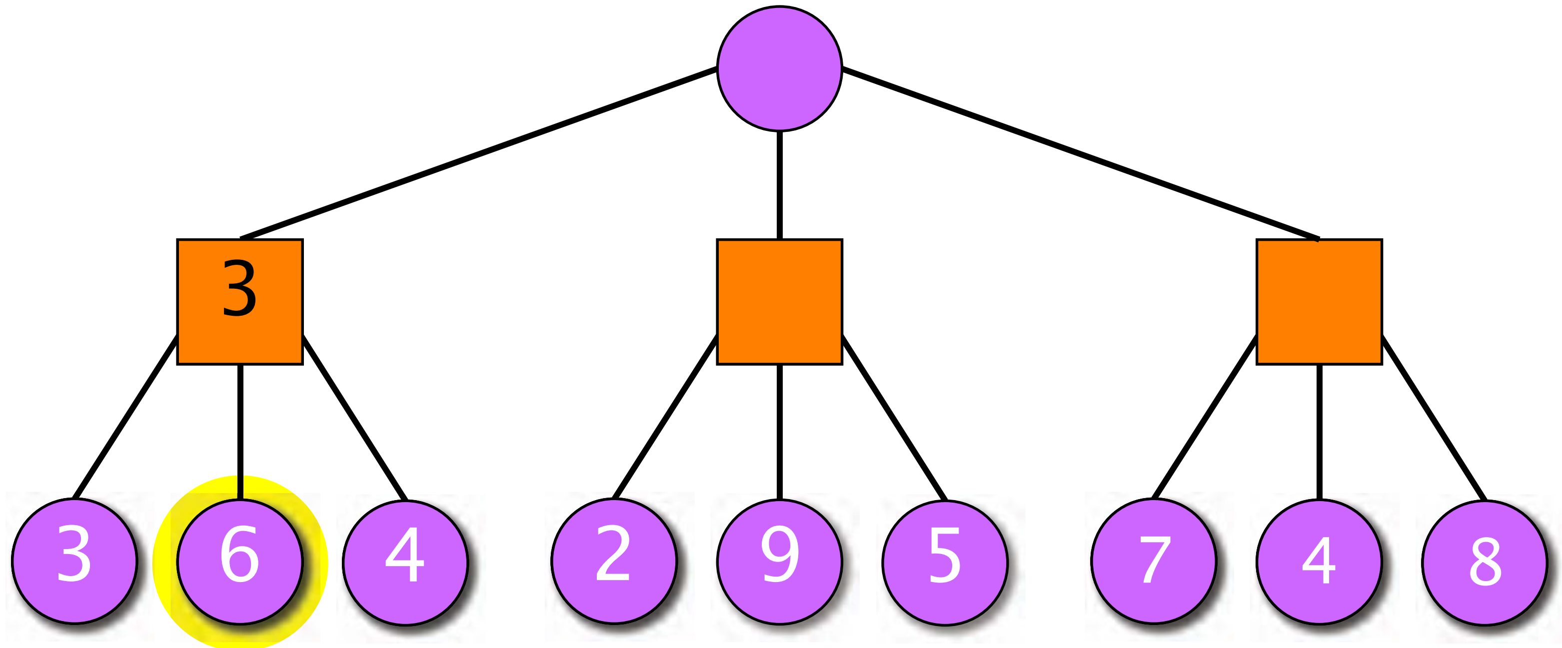

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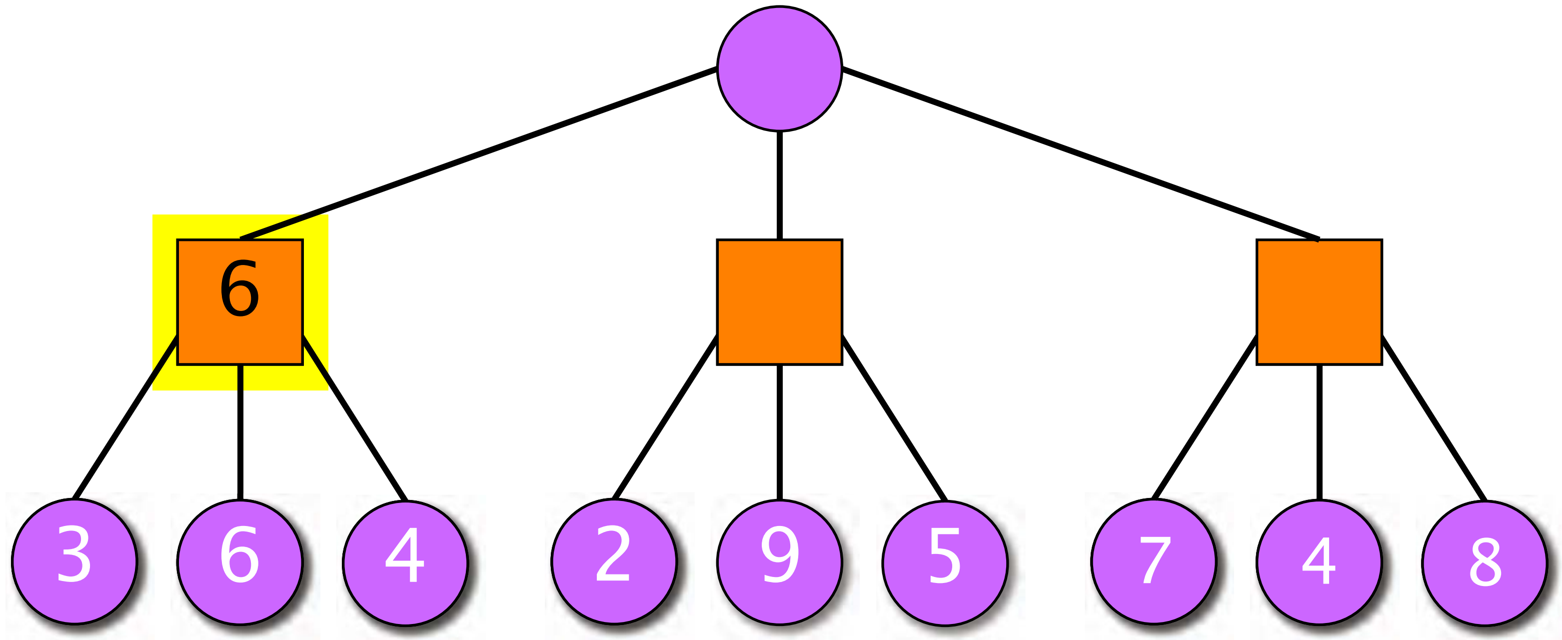

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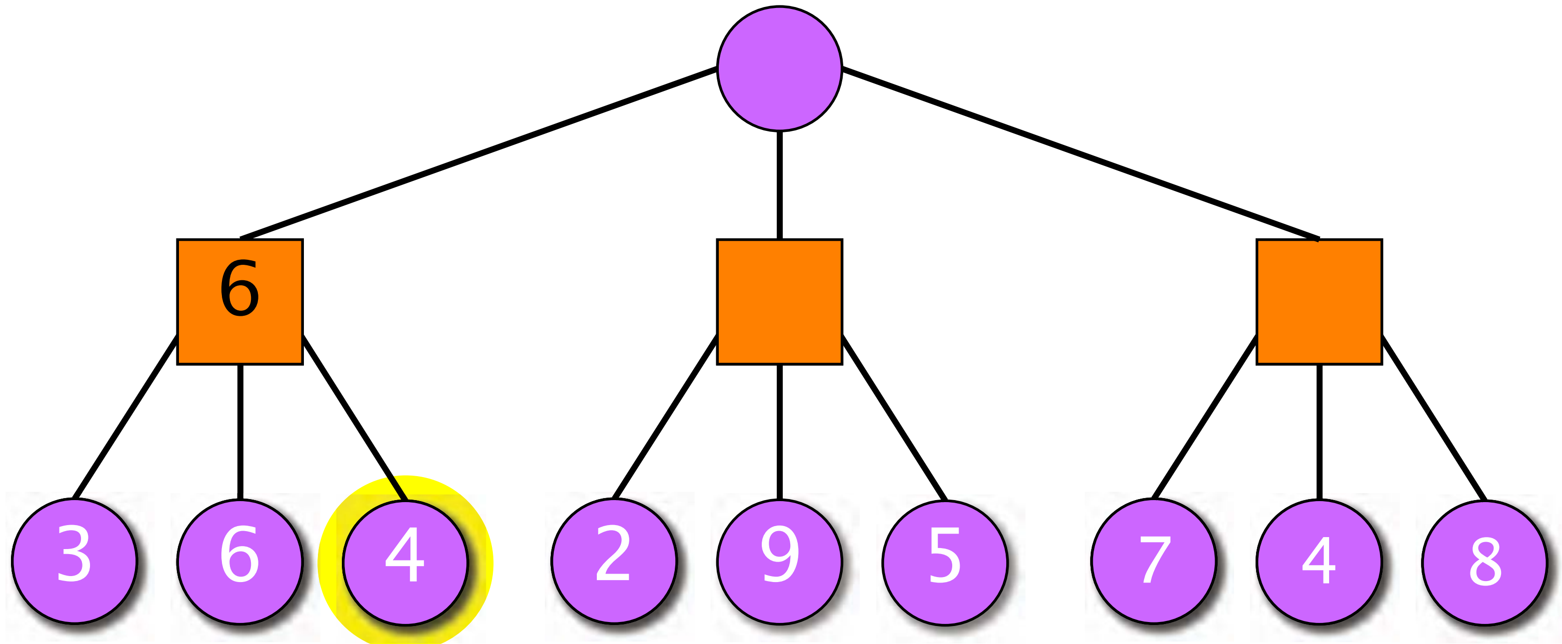

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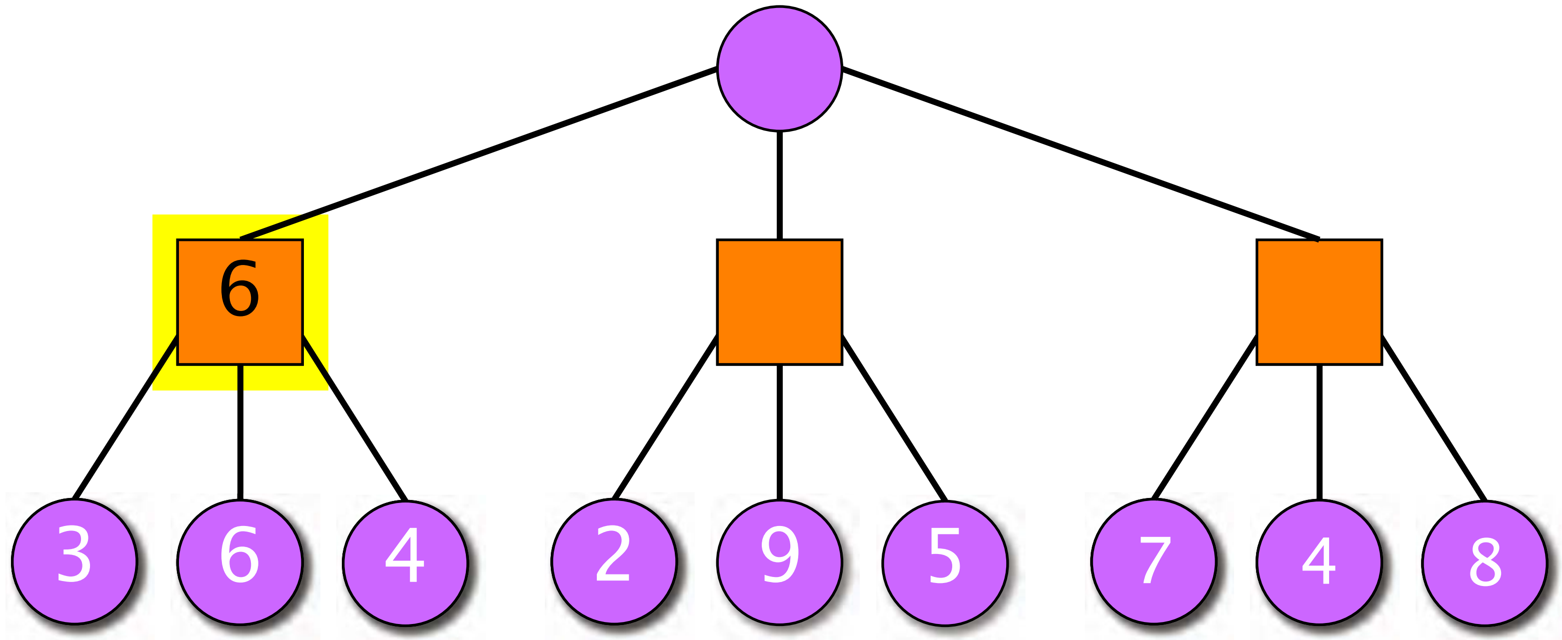

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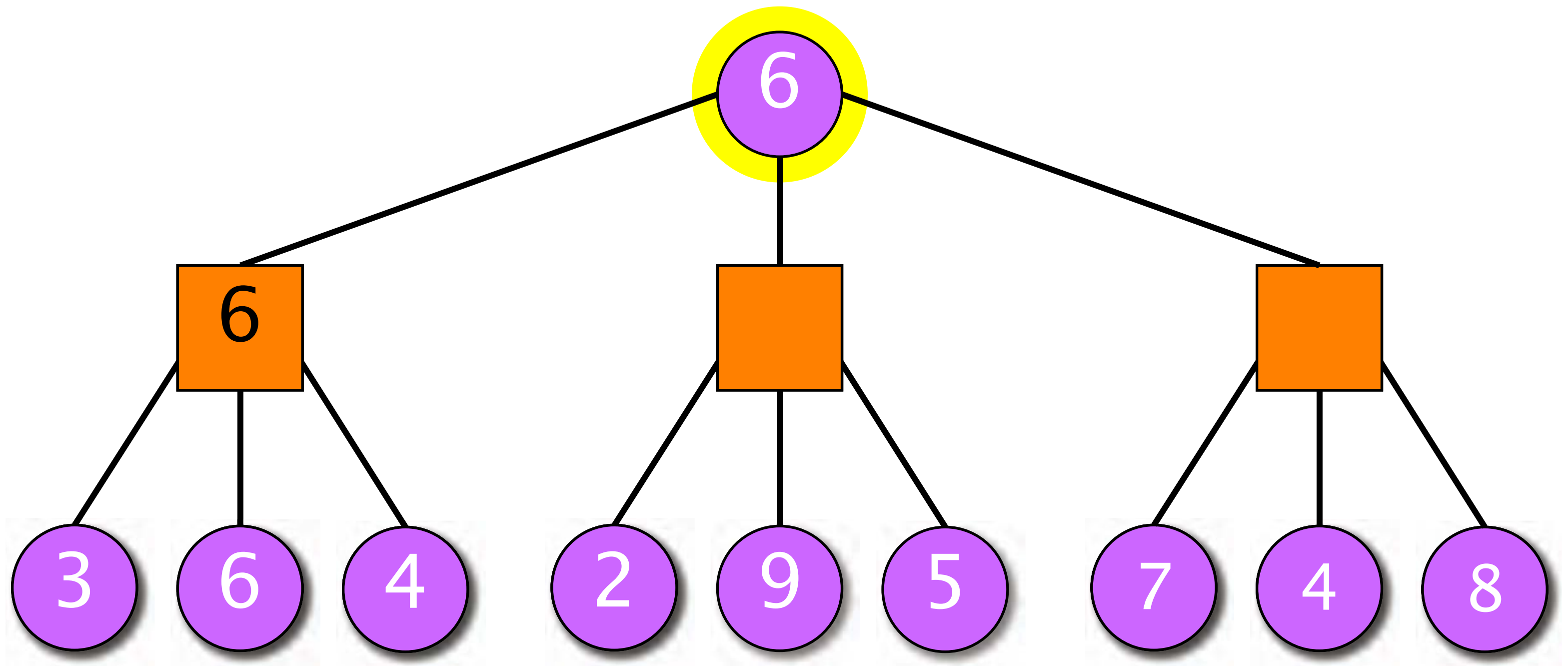

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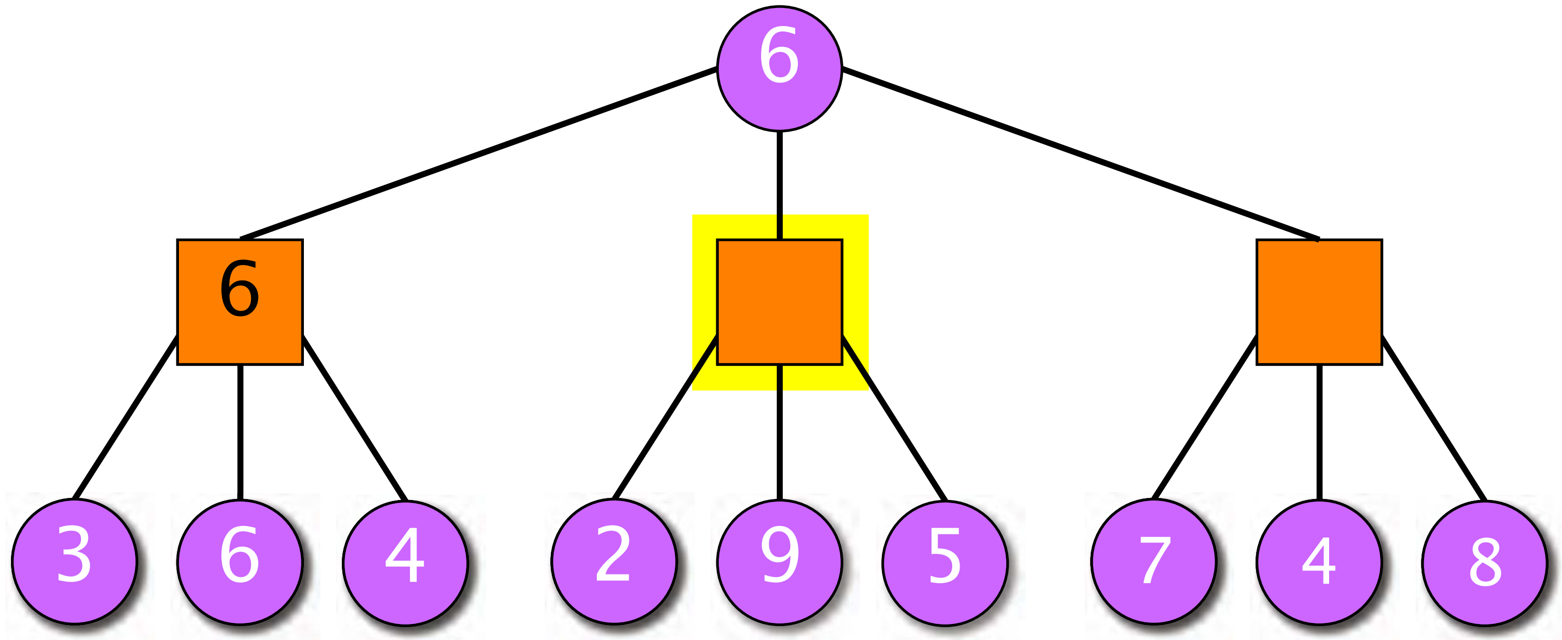

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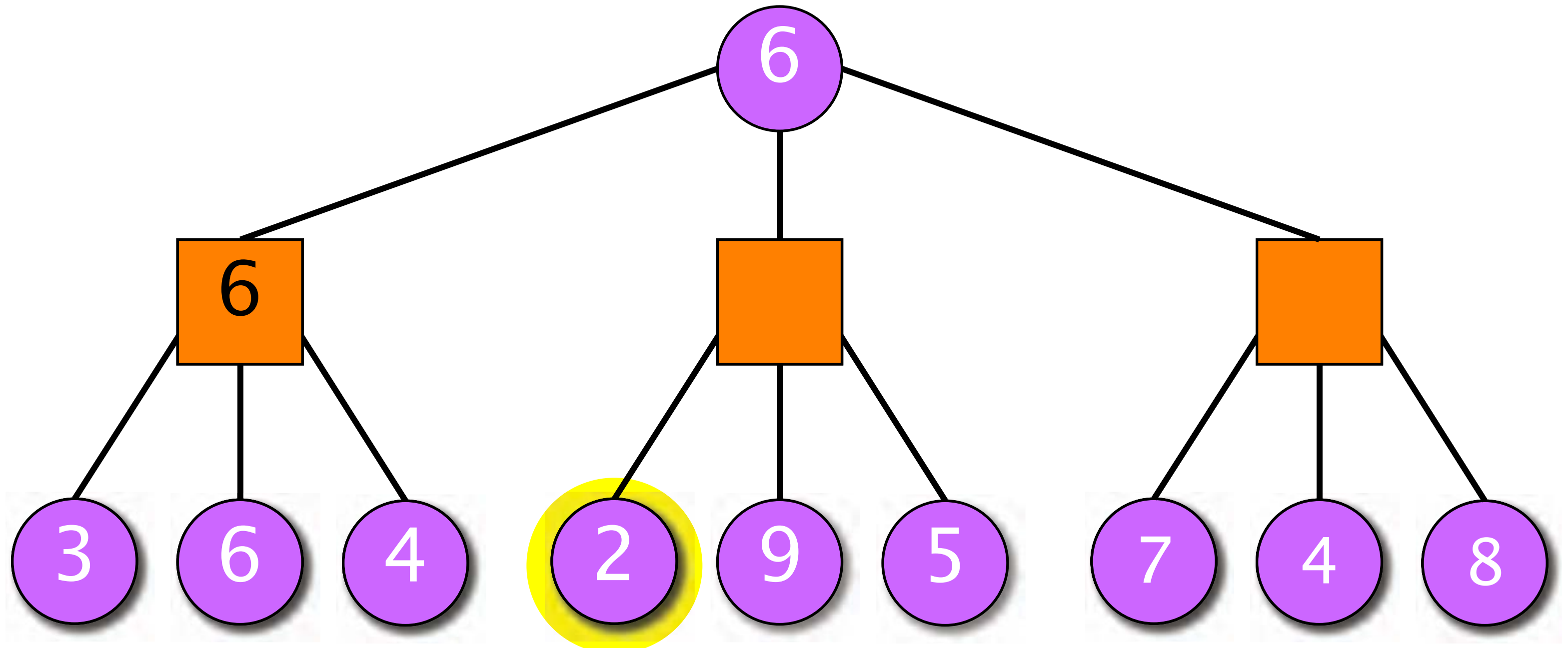

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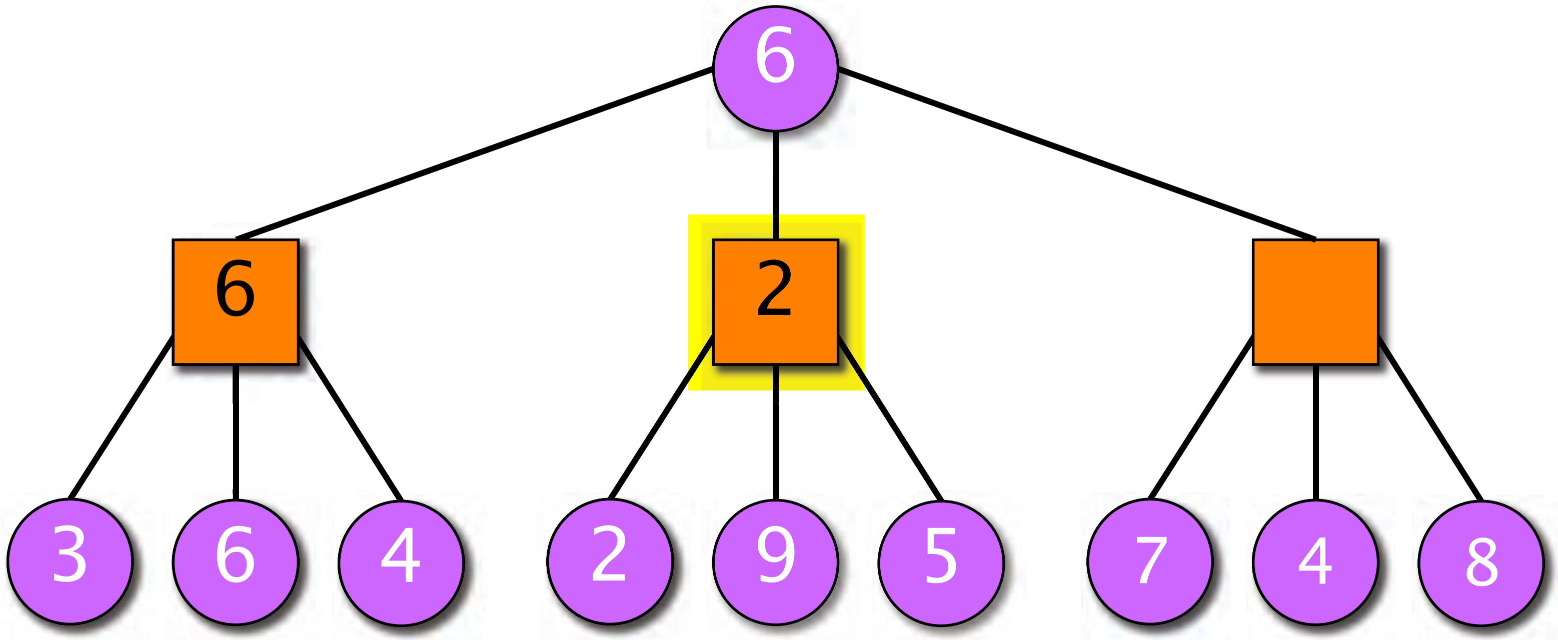

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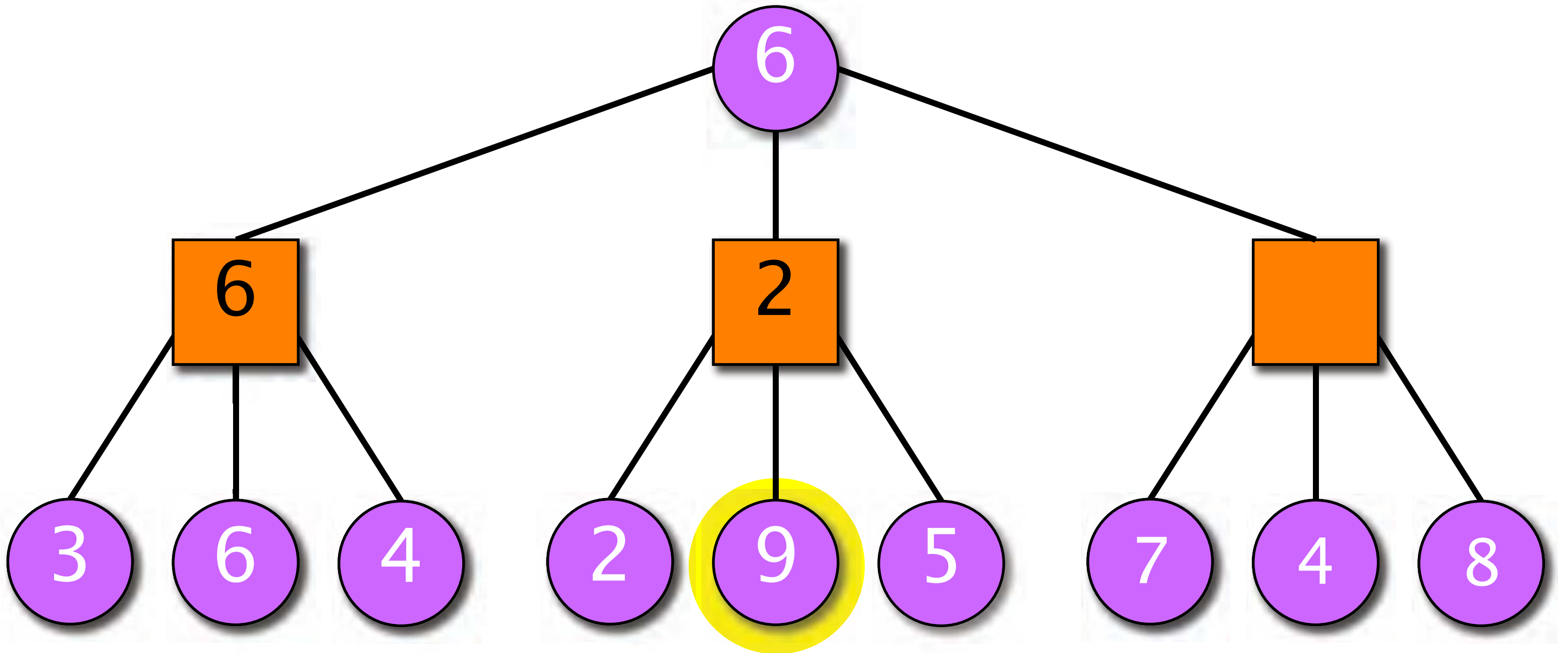

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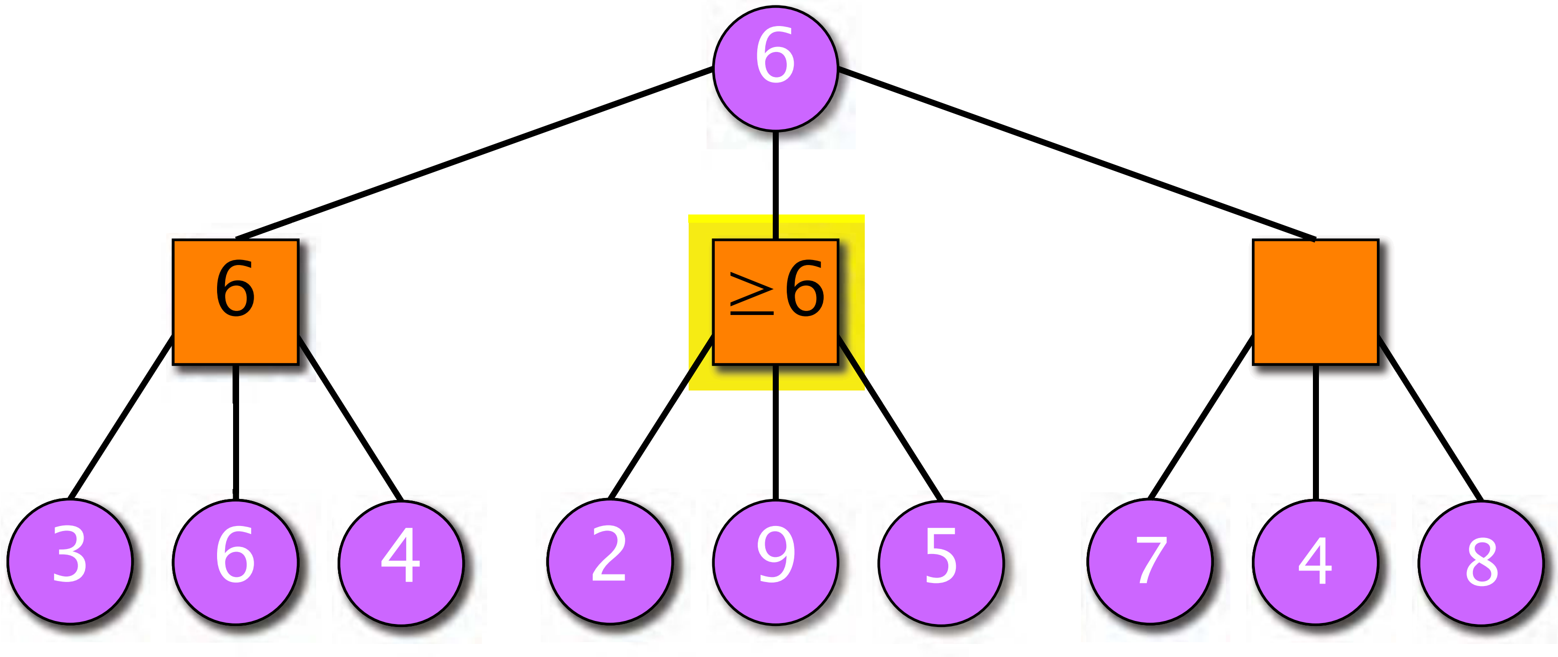

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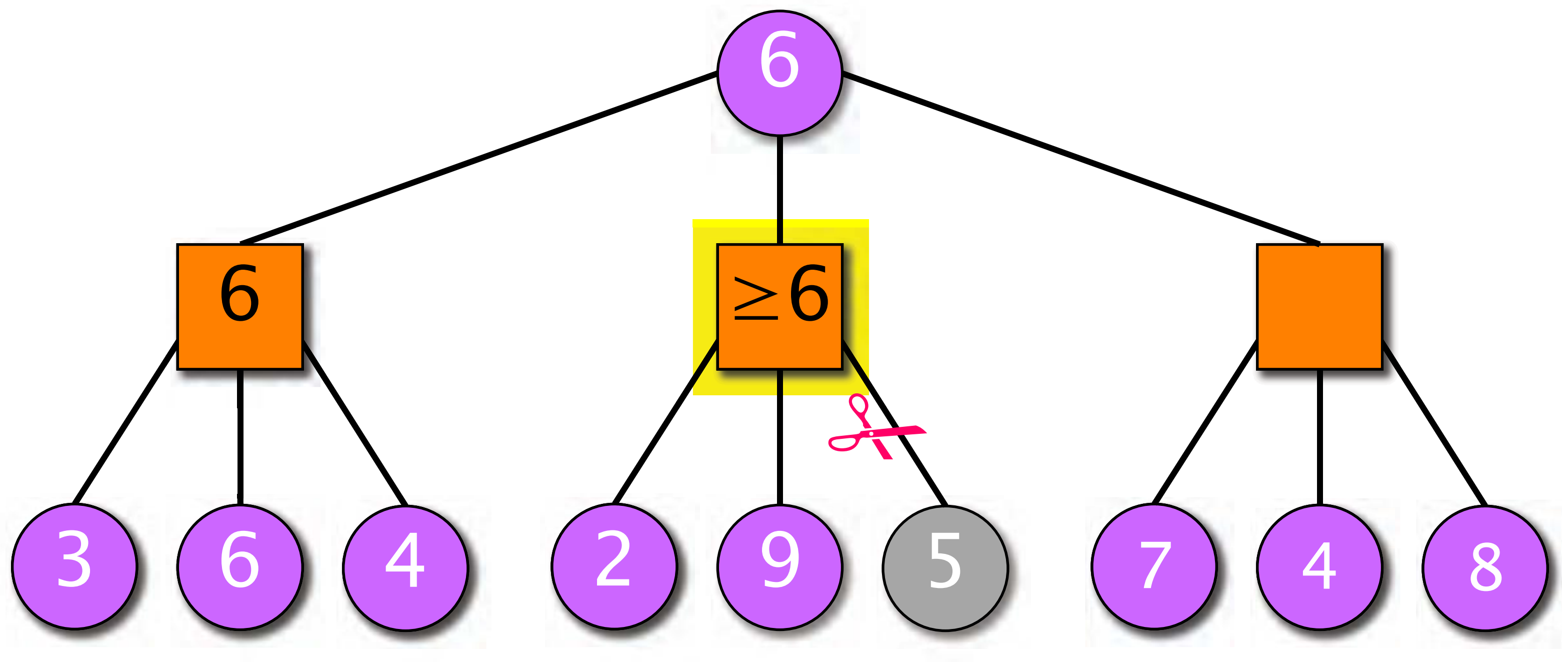

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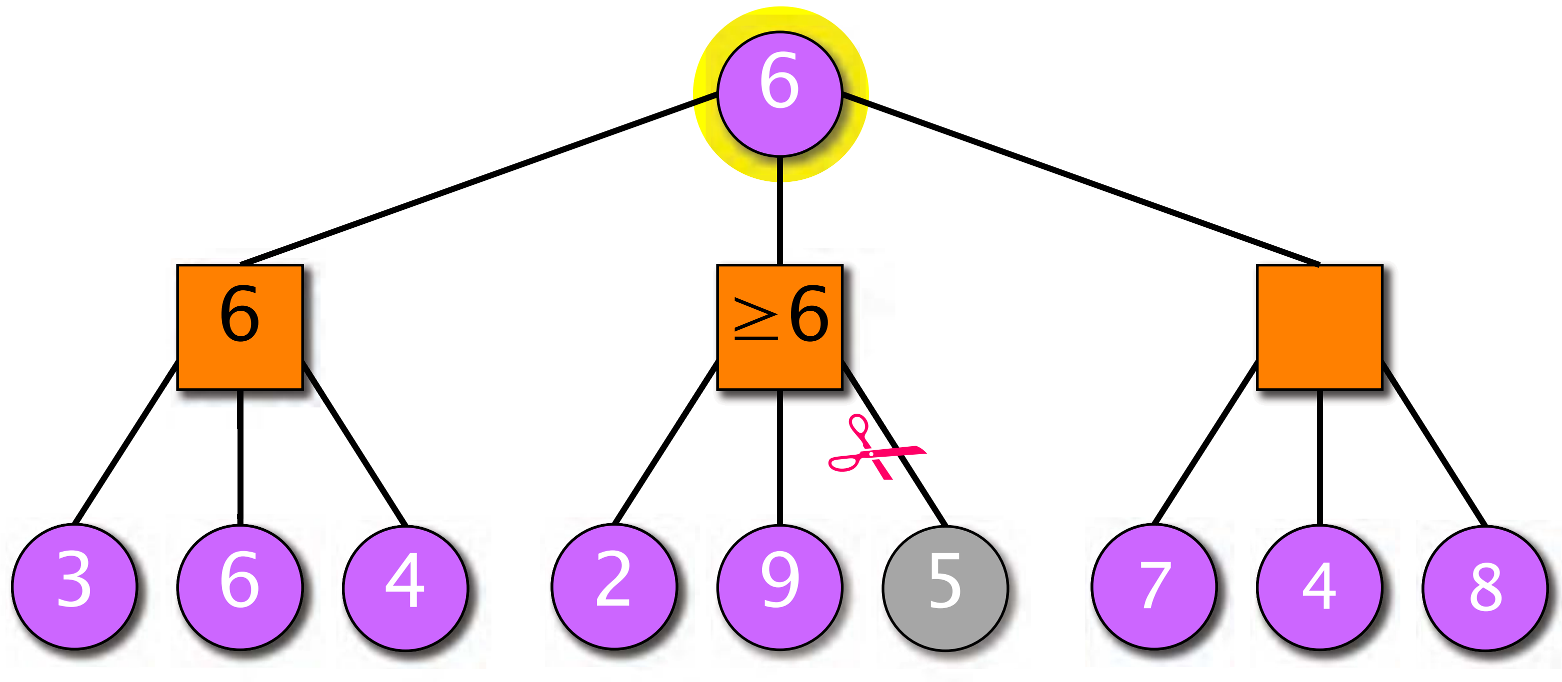
Alpha–Beta Pruning



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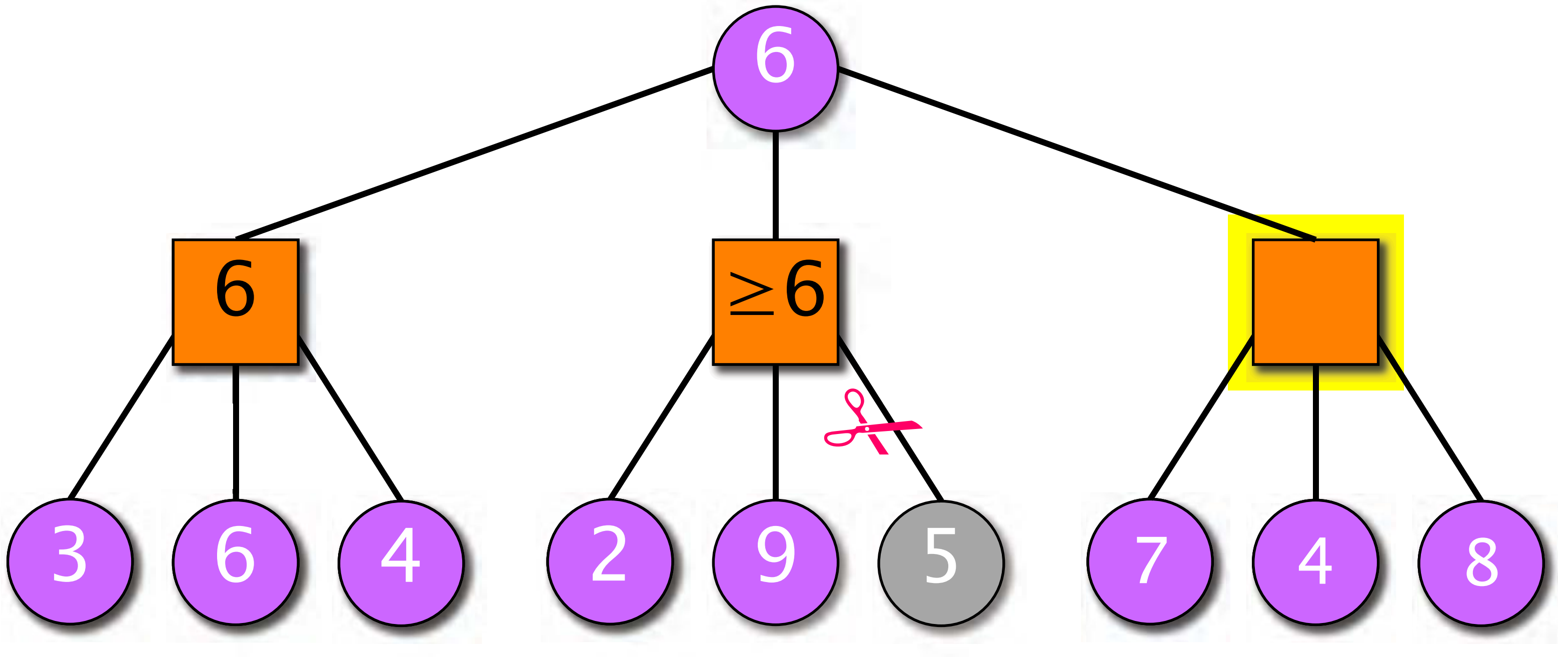

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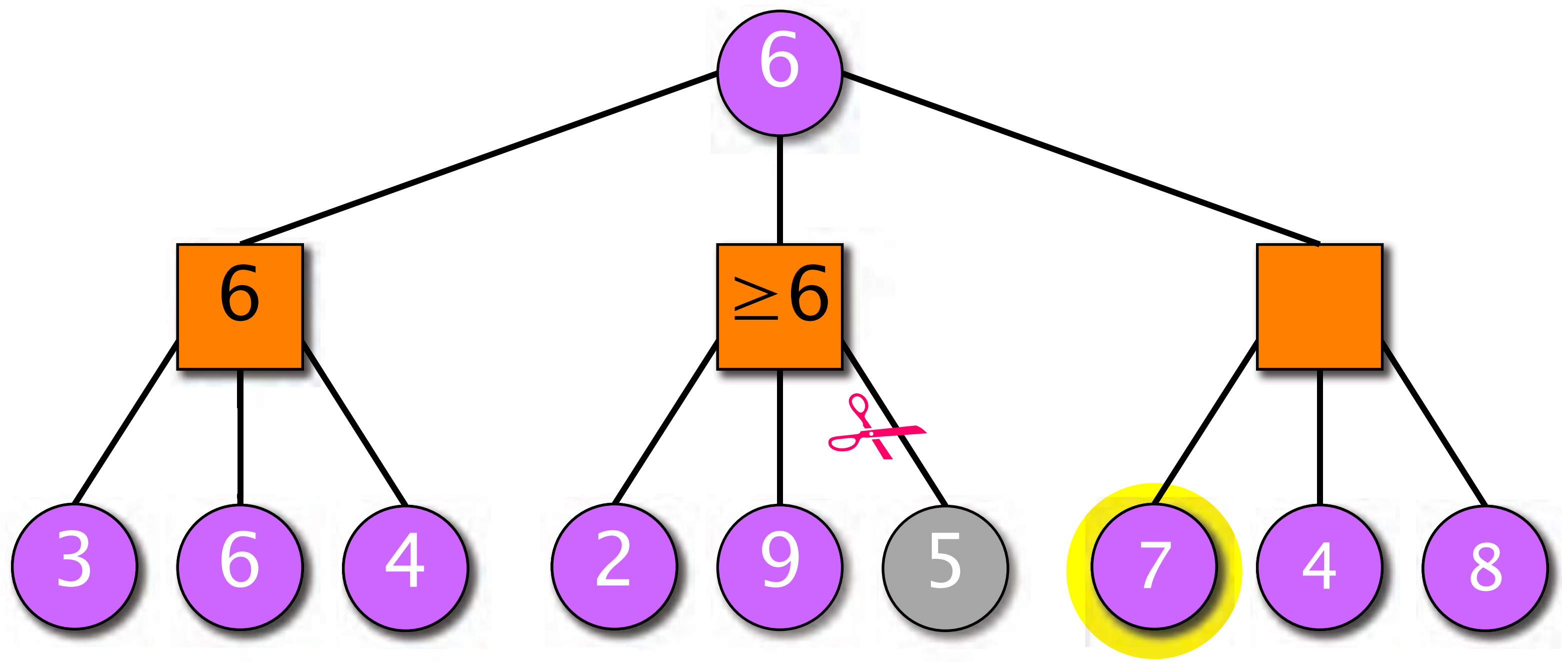

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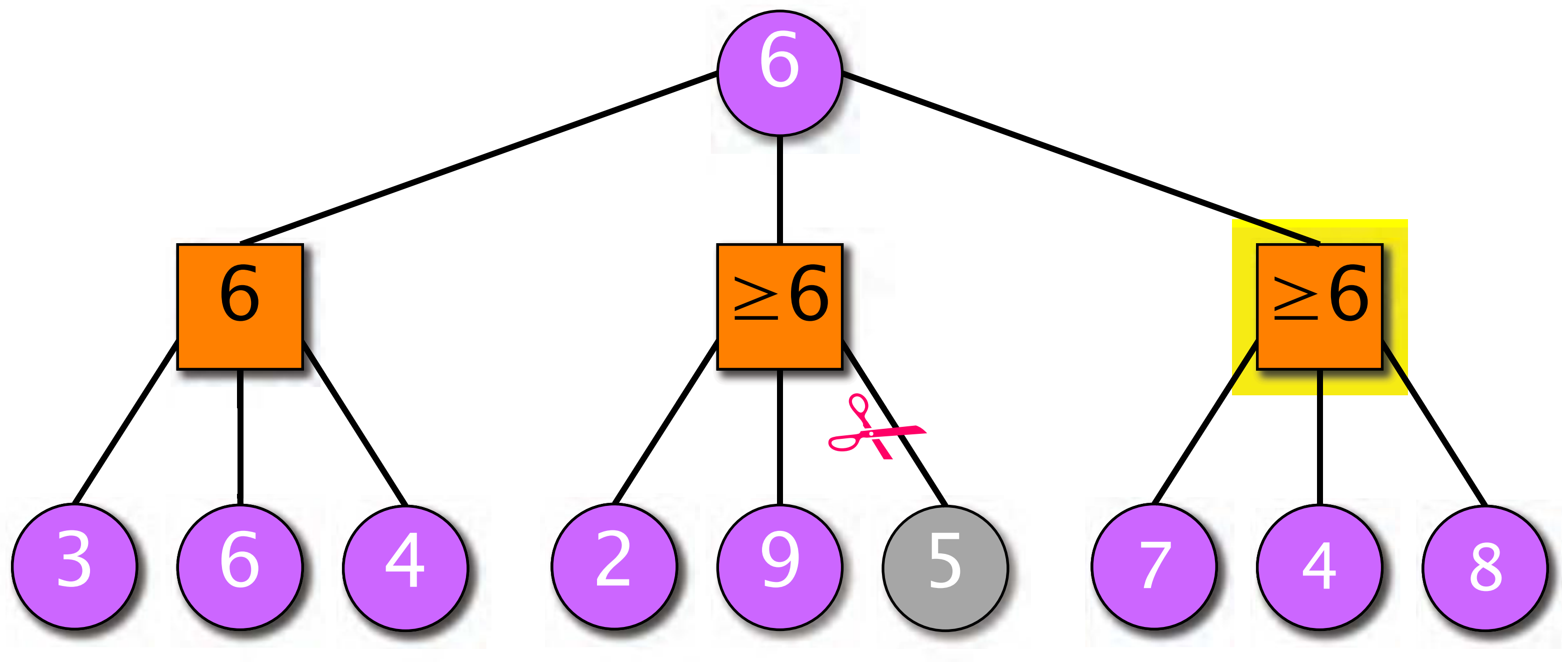

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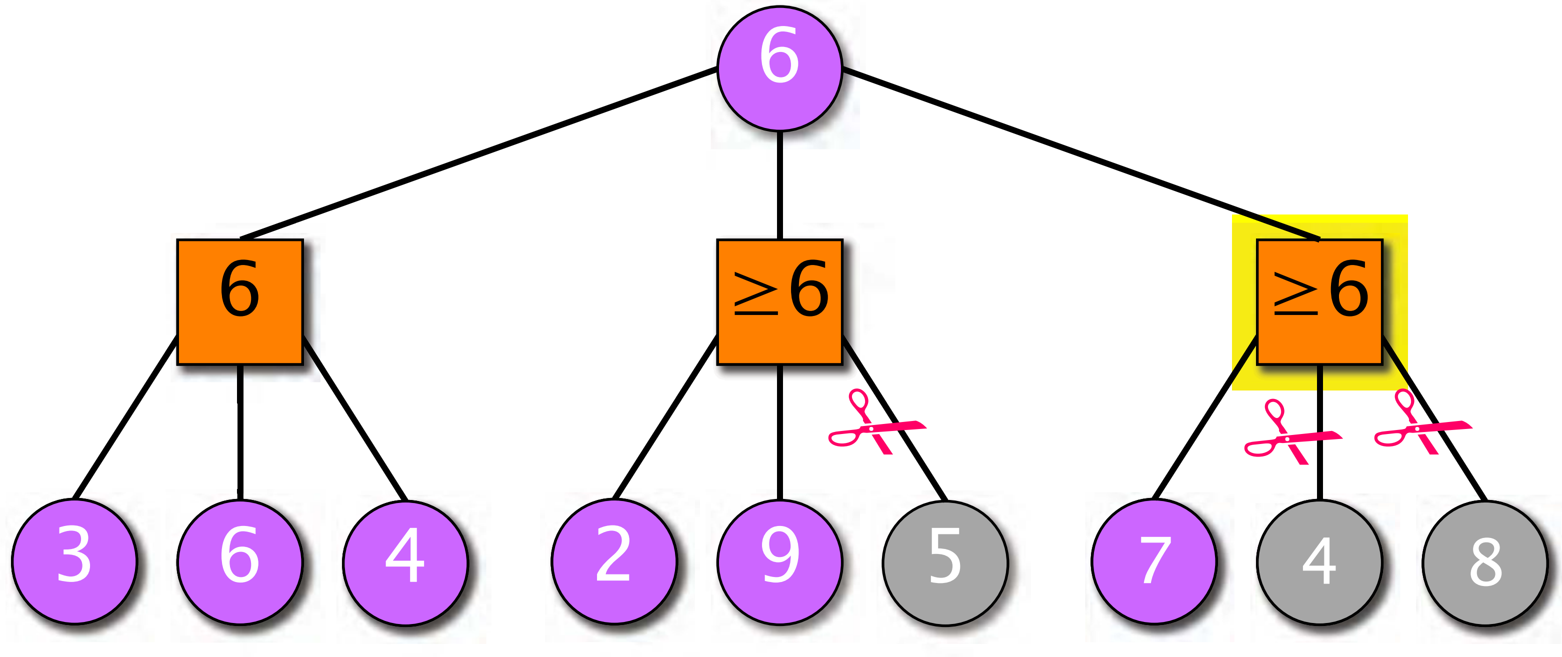

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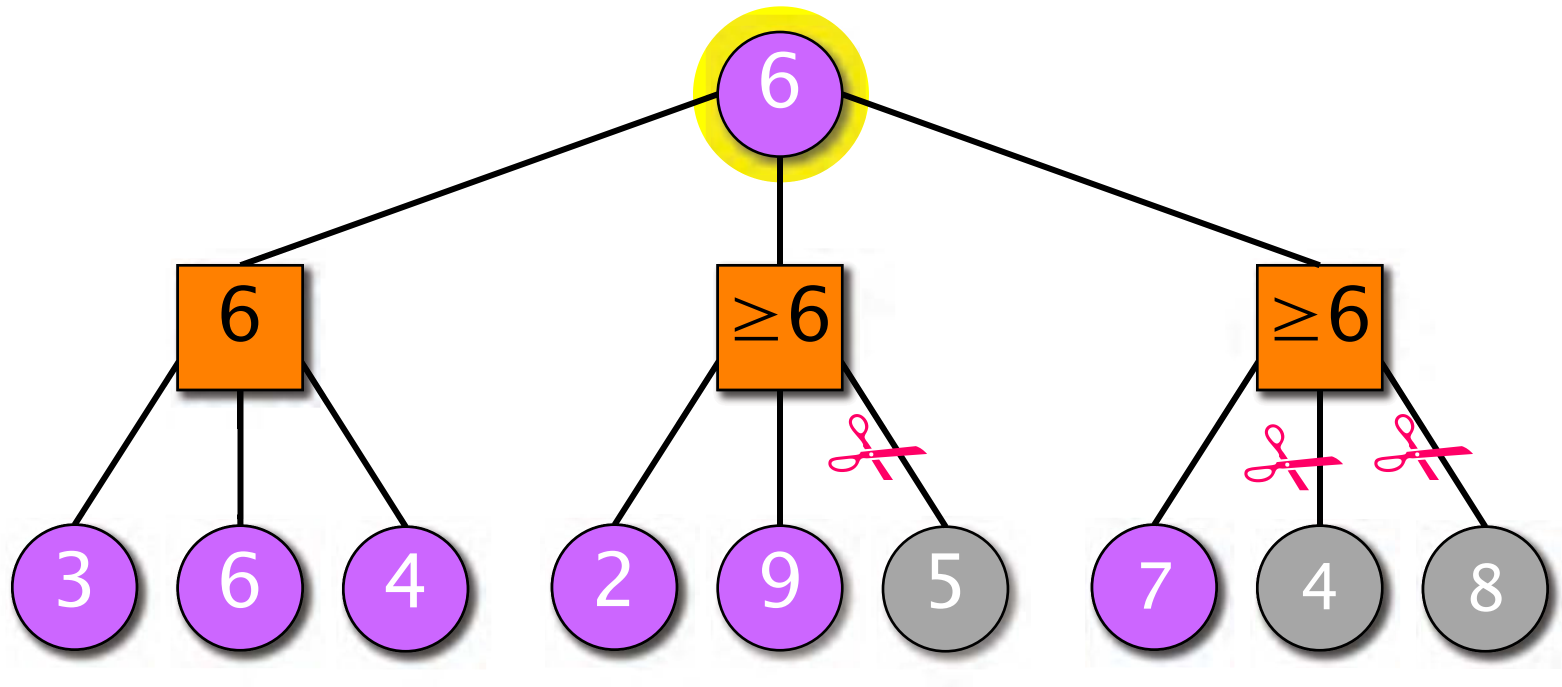

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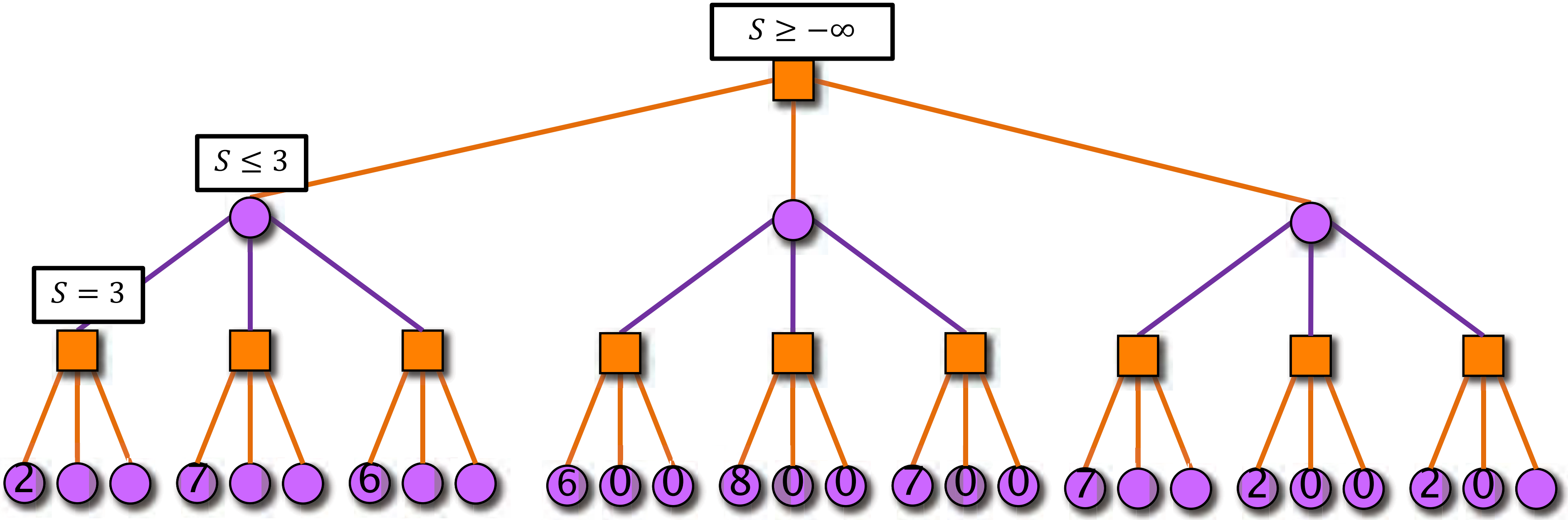

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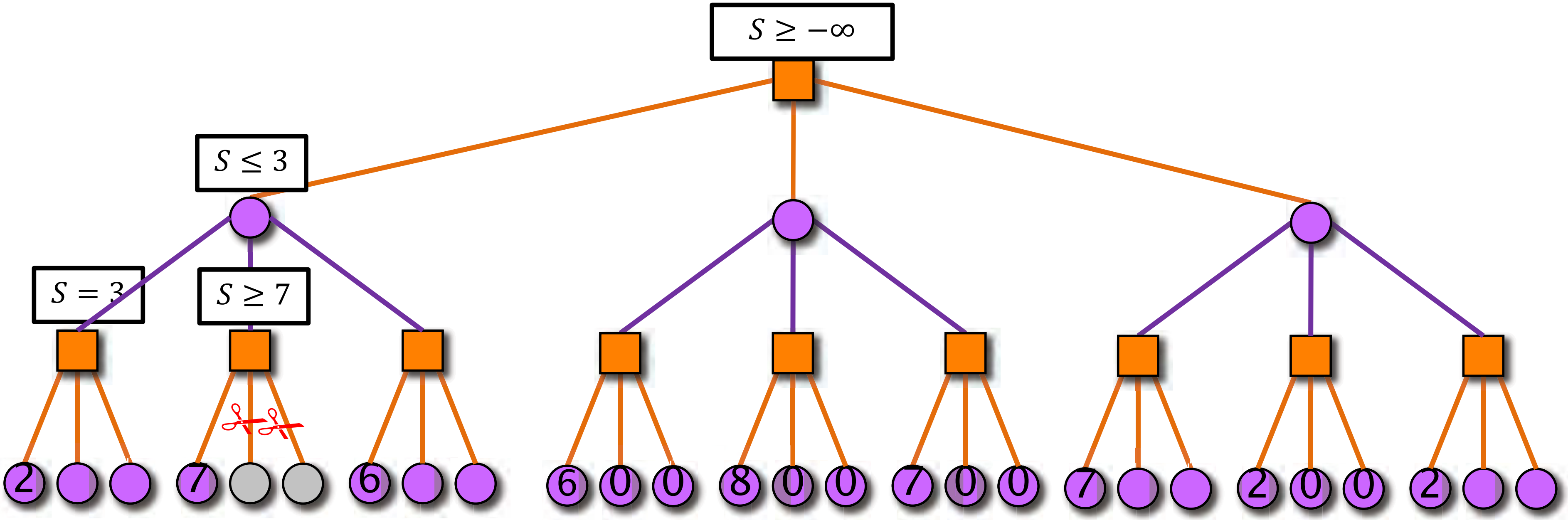

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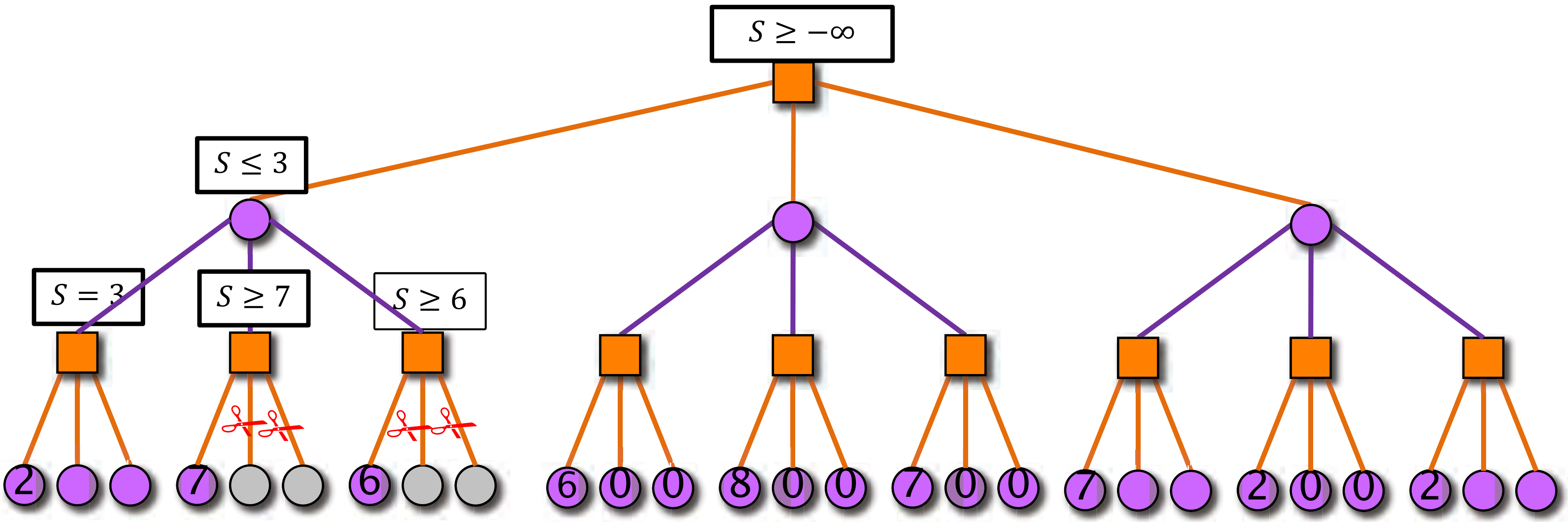

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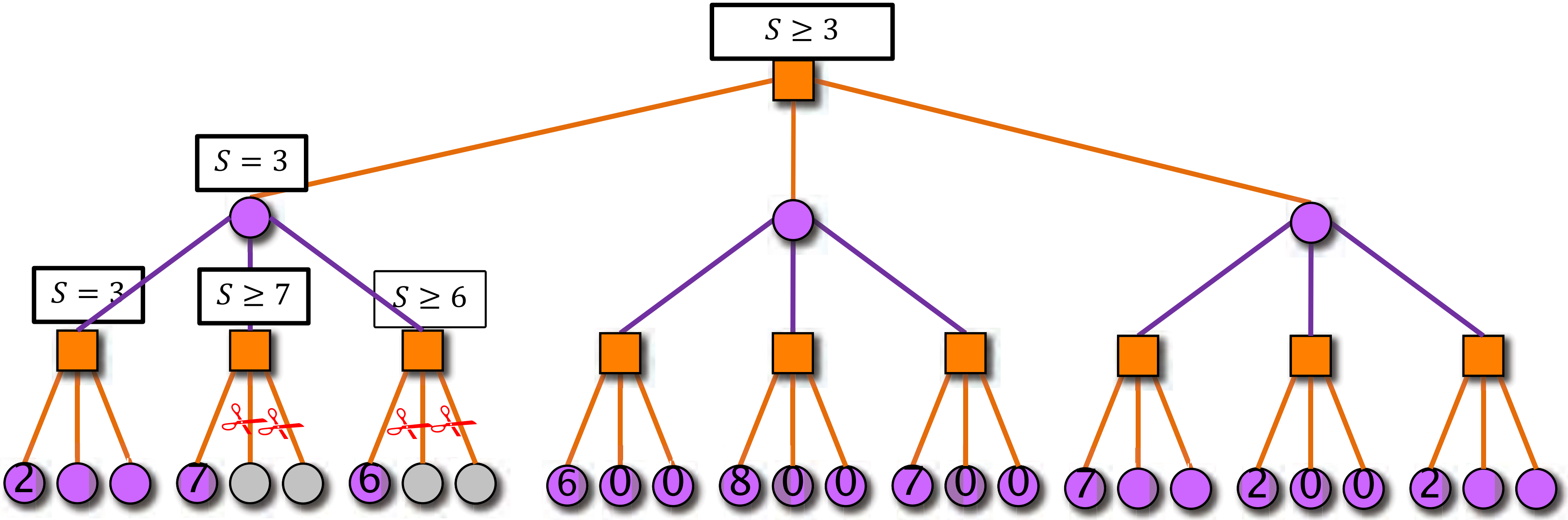

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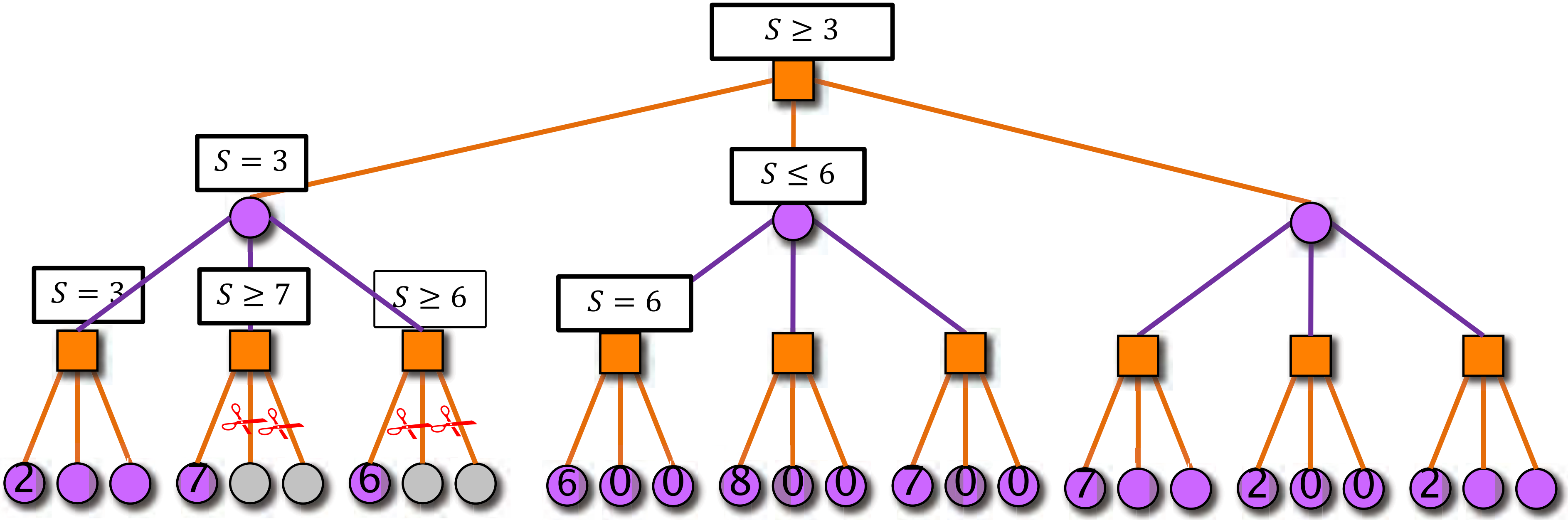

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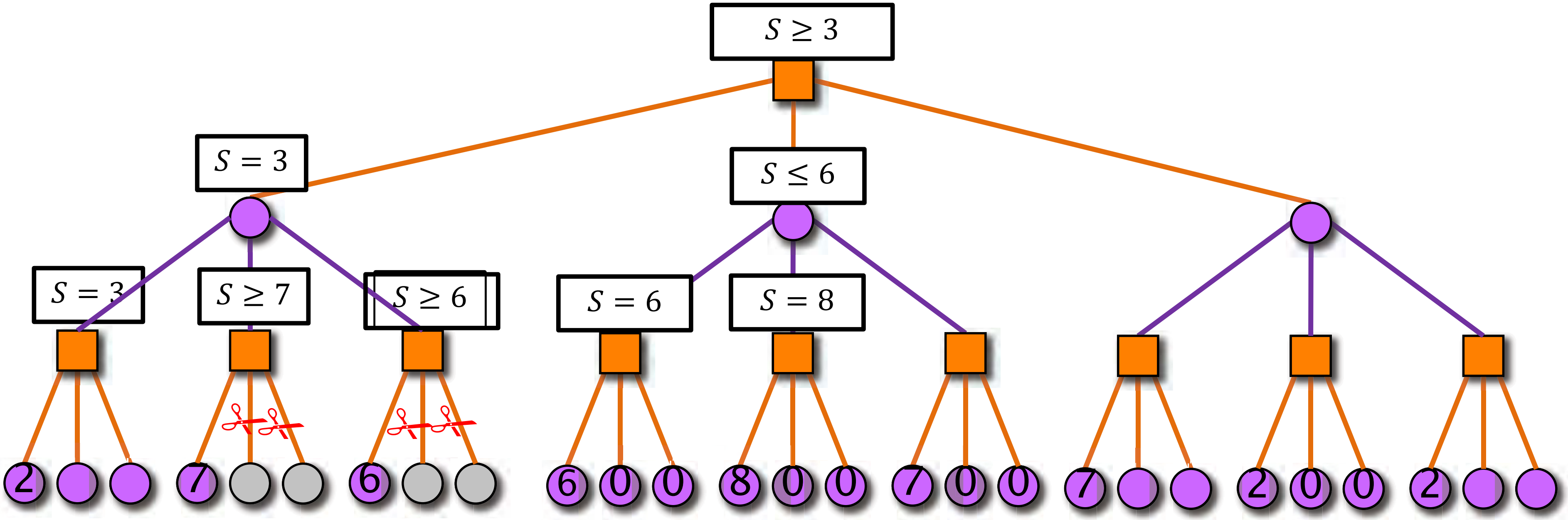

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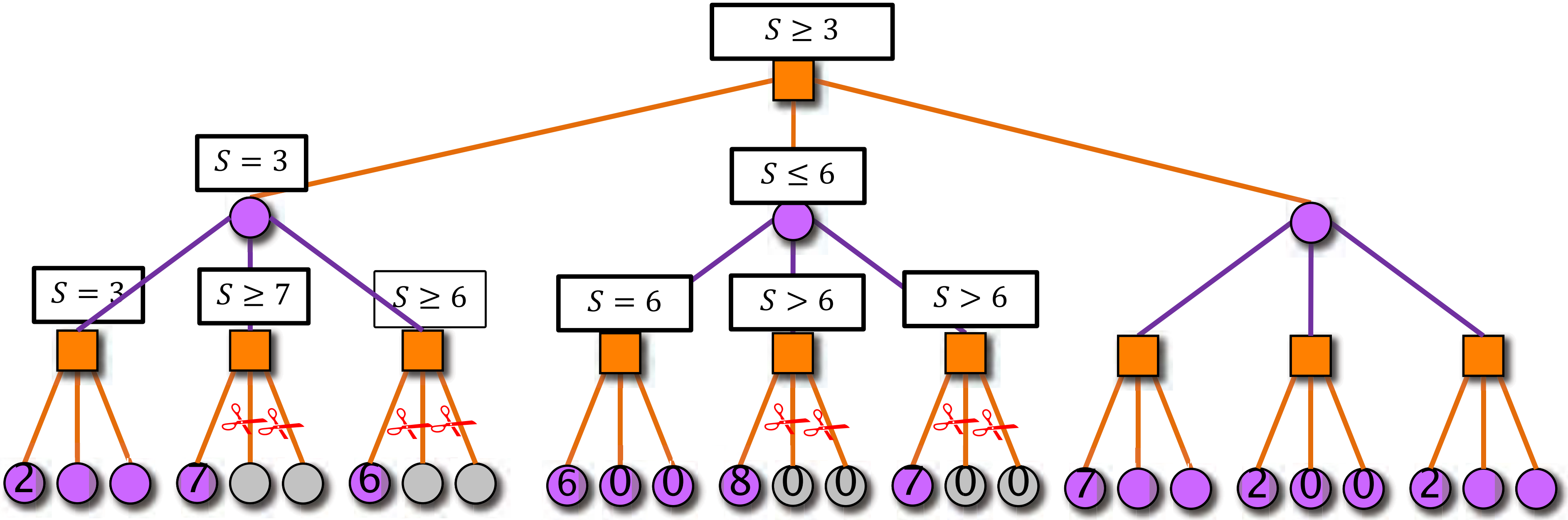

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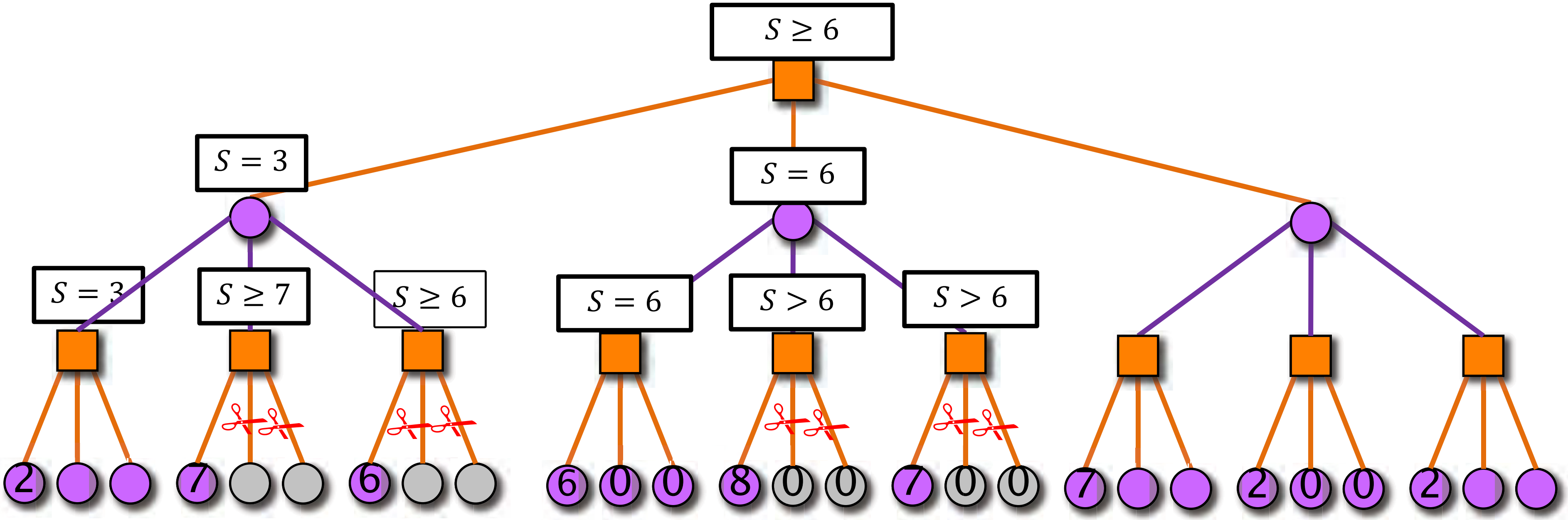

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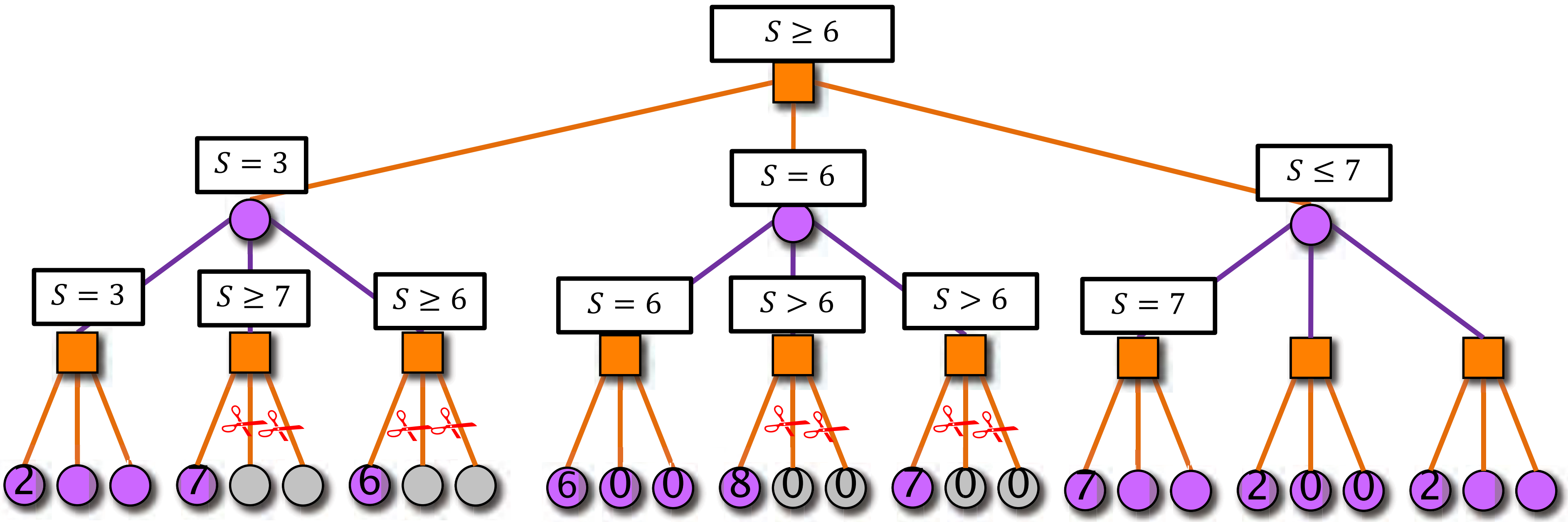

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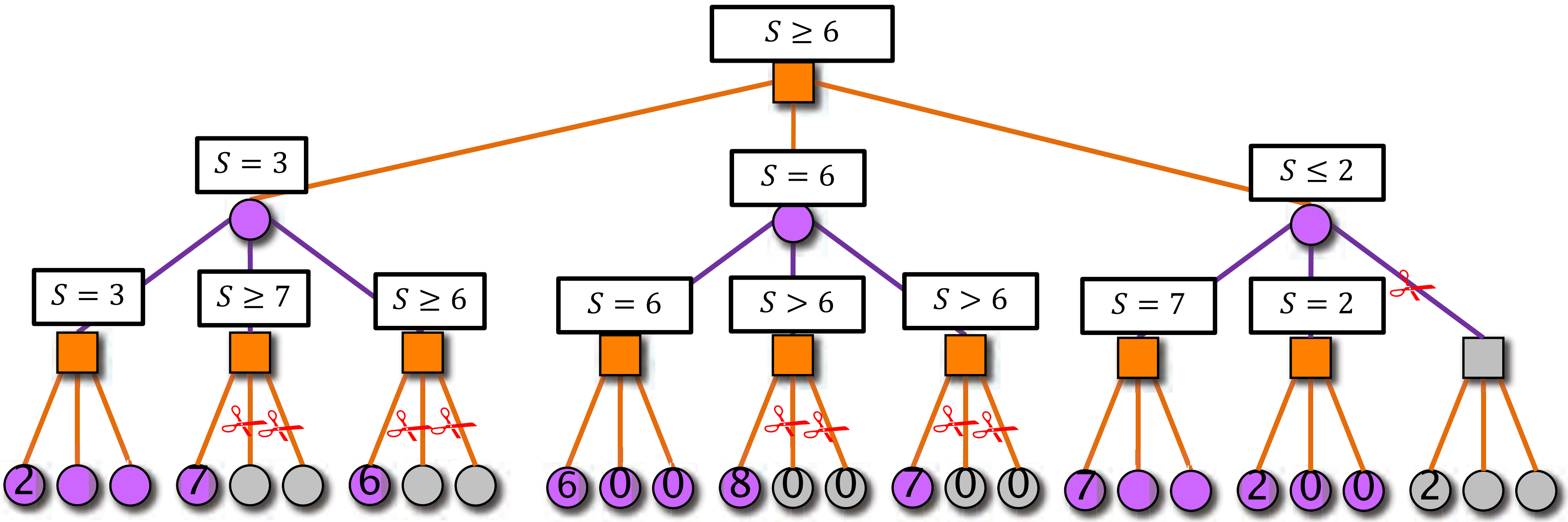
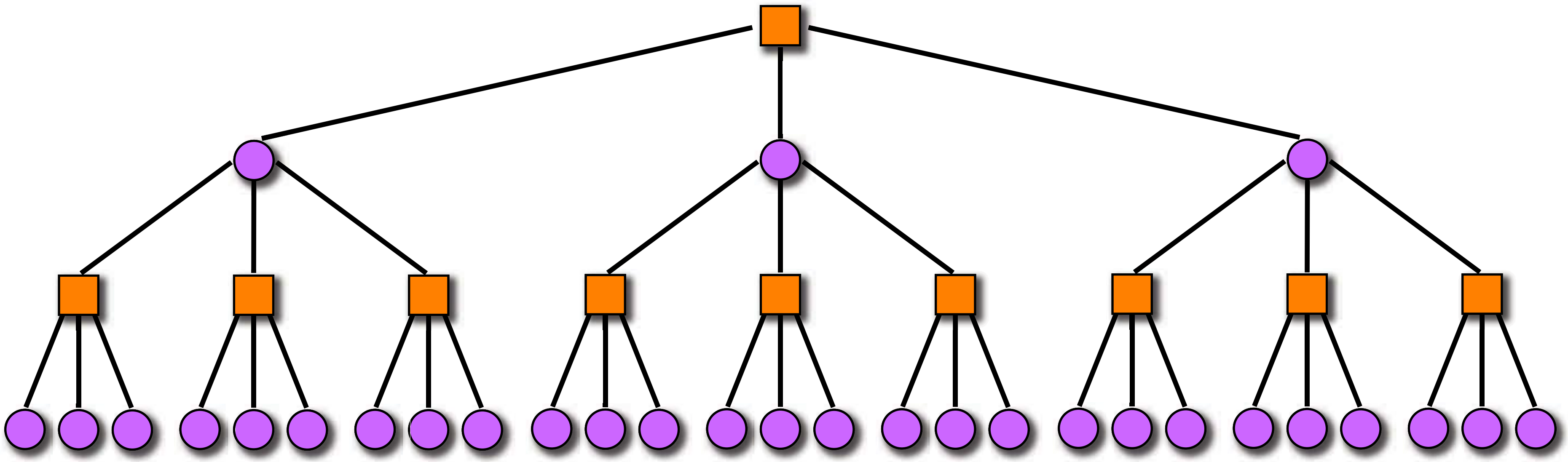


11 Leaves Pruned

Alpha-Beta Analysis



Theorem [KM75]. For a game tree with branching factor b and depth d, an alpha-beta search with moves searched in best-first order examines exactly $b^{\lceil d/2 \rceil} + b^{\lfloor d/2 \rfloor} - 1$ nodes at ply d. ■

The naive algorithm examines b^d nodes at ply d. For the same work, the search depth is effectively doubled. For the same depth, the work is square-rooted.

Code for Alpha-Beta Pruning

```
int search( searchNode* node, int depth ) {

 move_list = get_moves(node);
 int score = eval(node->position)

 if (abs(sc) >= MATE || depth <=0){
   // Leaf node
   return score;
 }
 // Negascout
 node->alpha = -node->parent->beta;
 node->beta = -node->parent->alpha;
 // Create child node for searches.
 searchNode child;
 child.parent = node;
```

```
// struct searchNode{
//    searchNode* parent;
//    position_t position;
//    score_t alpha;
//    score_t beta;
//    bool abort;
//    score_t best_score;
// }
```

Code for Alpha-Beta Pruning

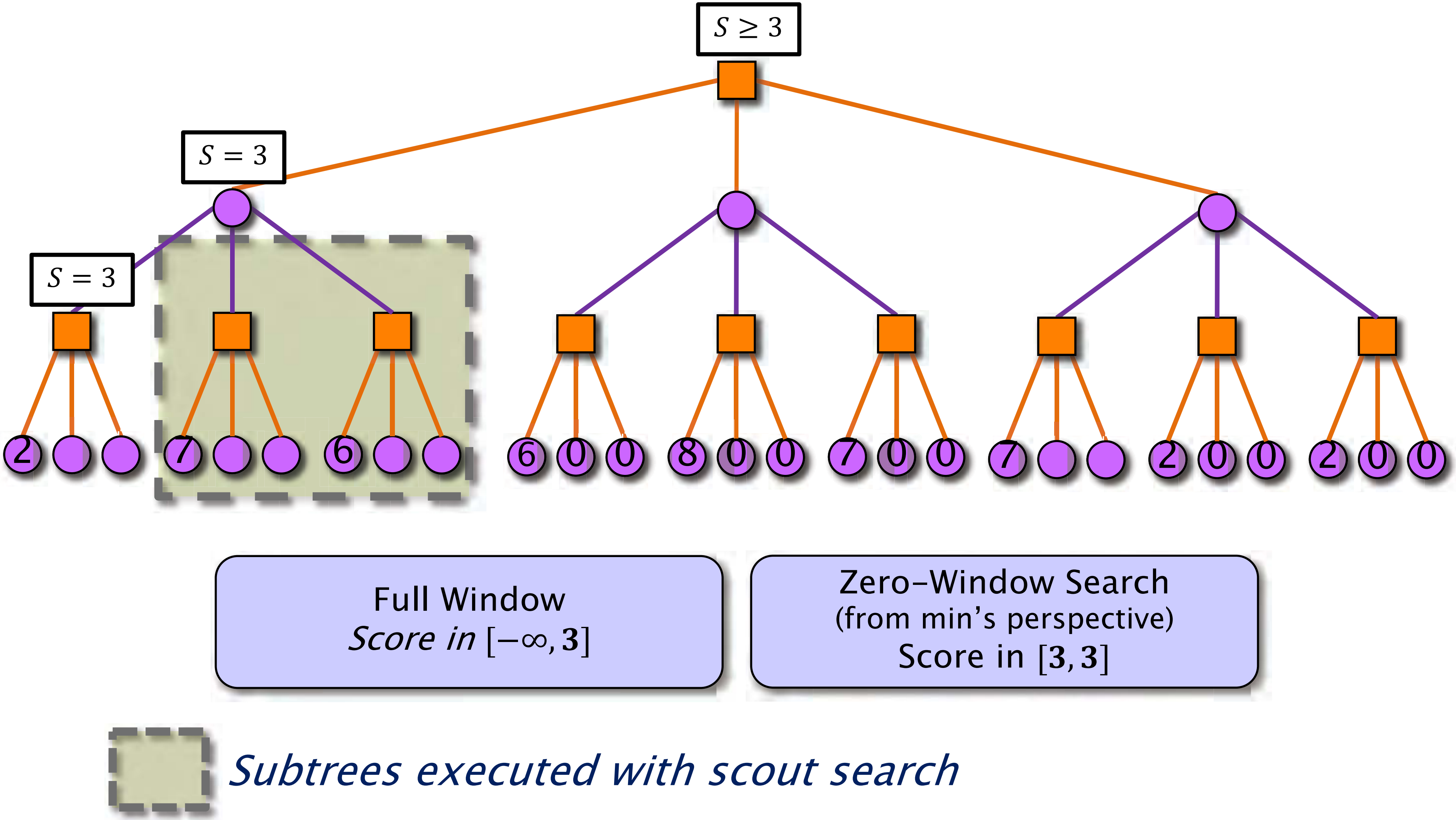
```
// Generate moves, hopefully in best-first order
  move_list = gen_moves(node->position);

  for ( mv in move_list)  {
    make_move(child.position, mv);
    // Search the child
    child_score = -search( &child, depth-1 );

    if ( child_score > node->best_score )
      node->best_score = child_score;
    if ( child_score >= node->beta ) /* beta cutoff */
      node->abort = true;
      break; // Early Exit!
    if ( child_score >= node->alpha )
      node->alpha = child_score
  }
  return node->best_score;
}
```

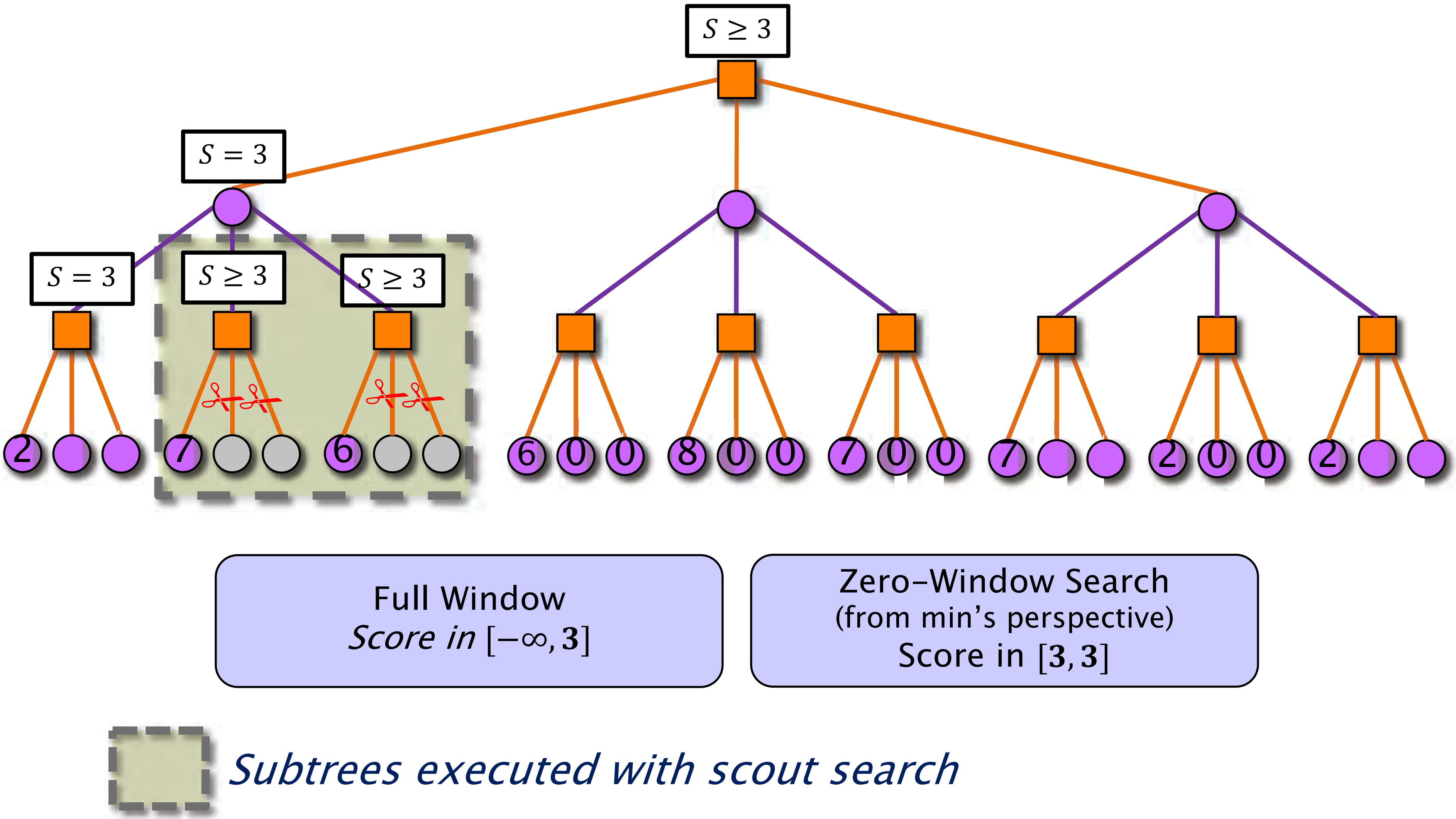
Principal Variation Search Pruning

Idea: Assume the first move is the best, and run scout search (“zero window” search) on the remaining moves to verify that they are worse.

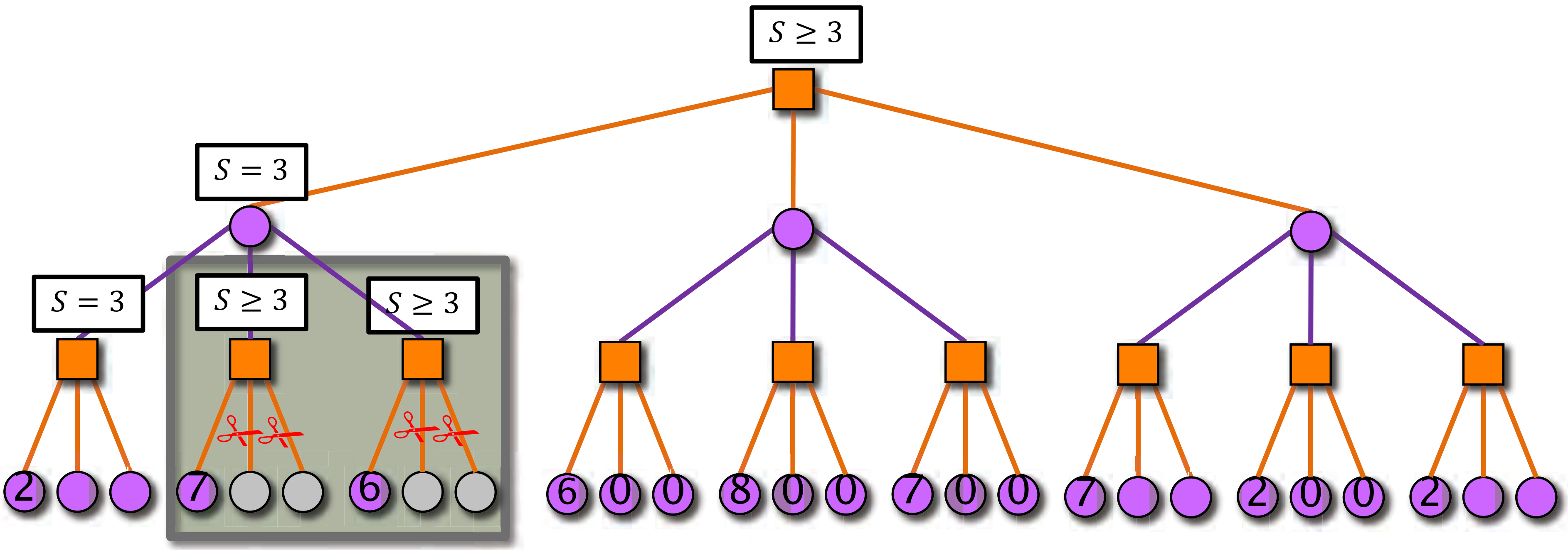


Principal Variation Search Pruning

Fail-Bad: If the zero window search returns a worse score than the first subtree, we can safely skip the full-window search in those subtrees.



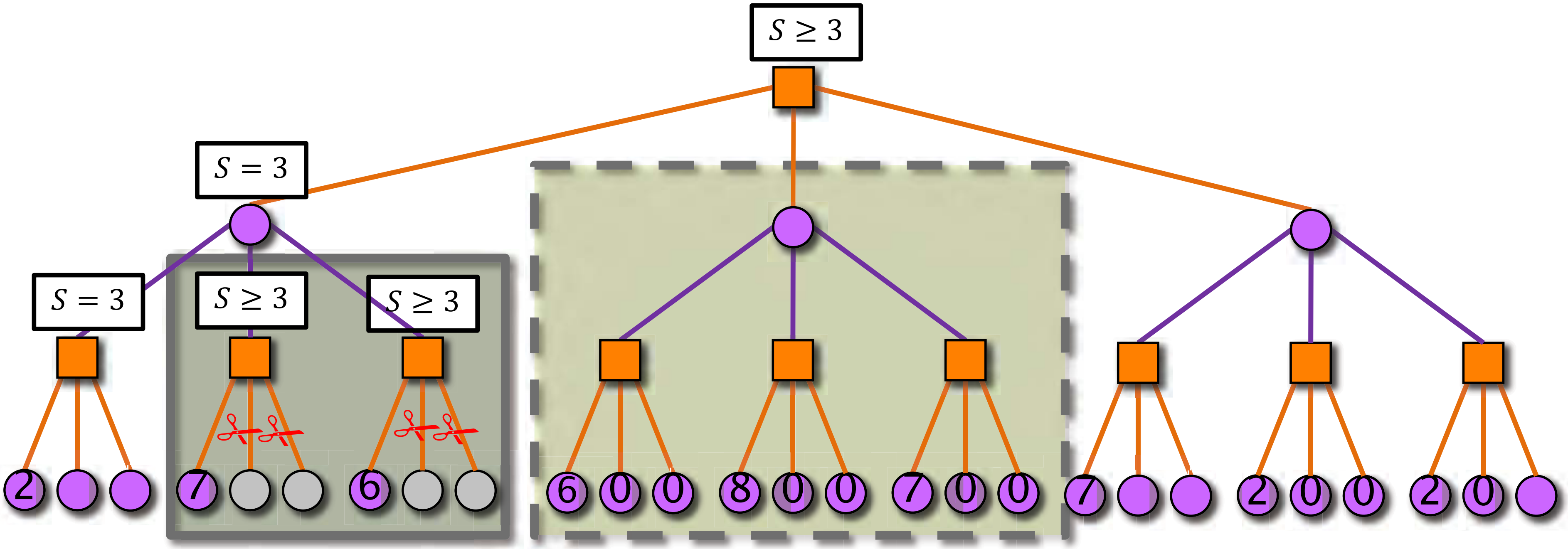
Principal Variation Search Pruning



Subtrees executed with scout search

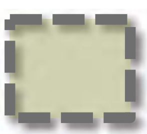
Principal Variation Search Pruning

Let's see a case where the scout search fails-good.



Full Window
Score in $[-\infty, 3]$

Zero-Window Search
(from min's perspective)
Score in $[3, 3]$



Subtrees executed with scout search

Principal Variation Search Pruning

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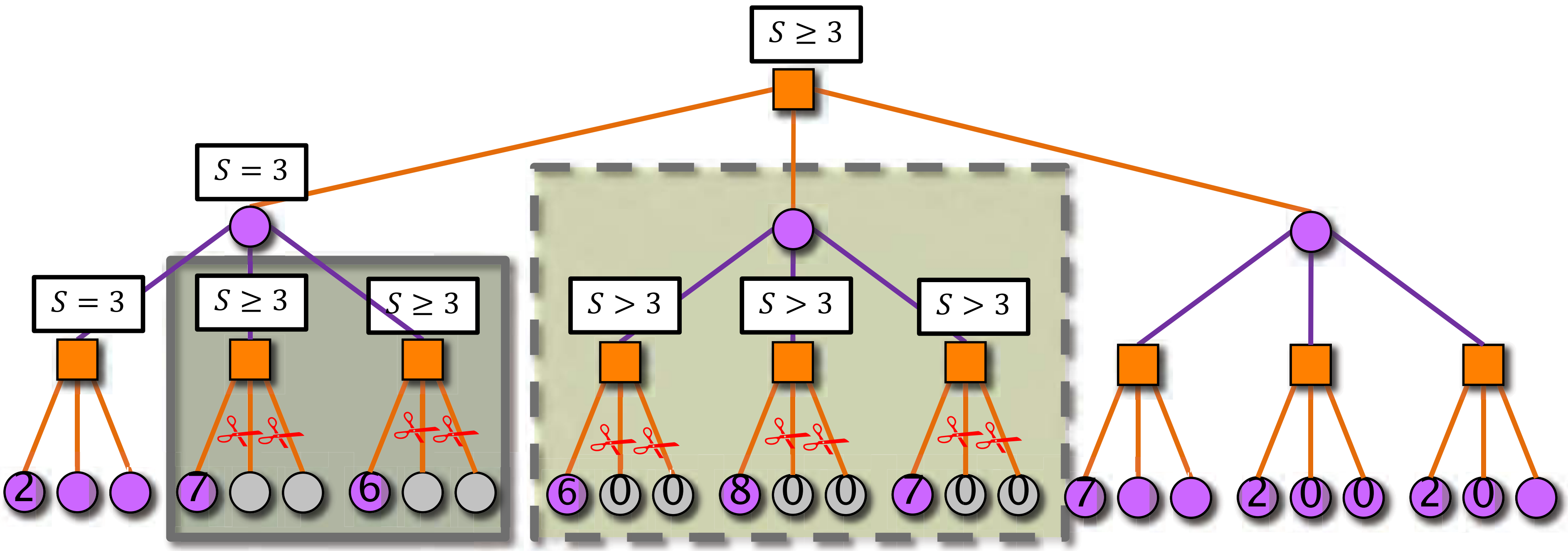


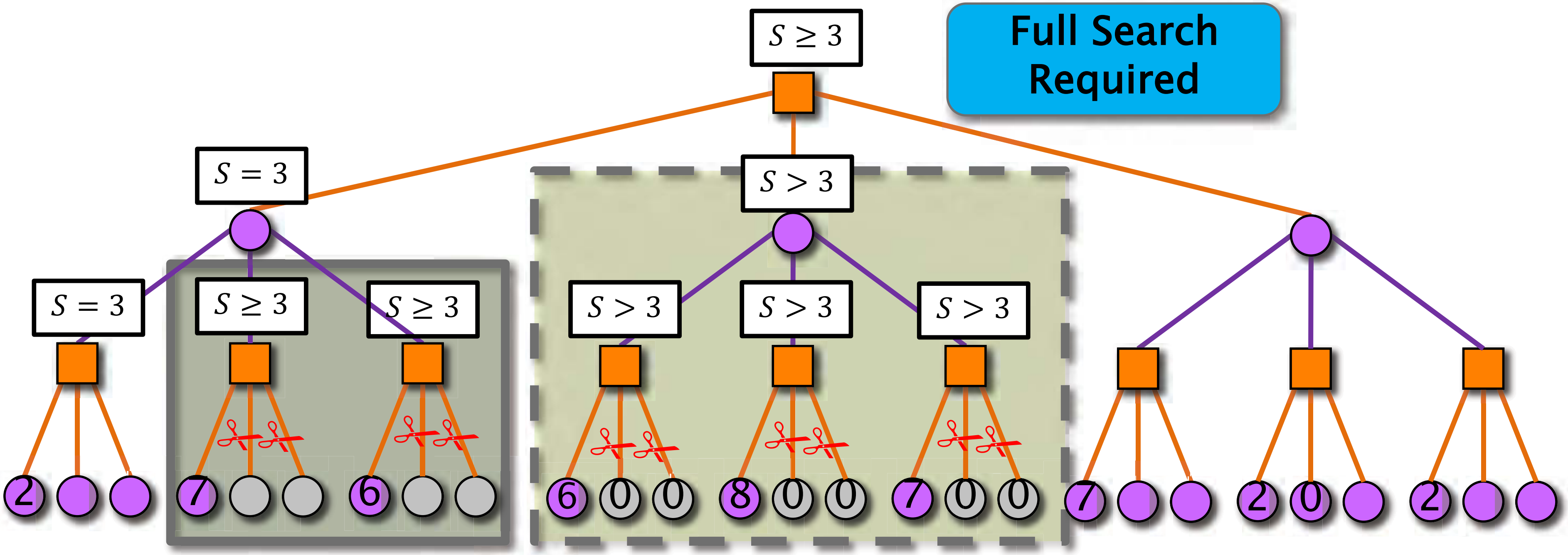
Full Window
Score in $[-\infty, 3]$

Zero-Window Search
(from min's perspective)
Score in $[3, 3]$

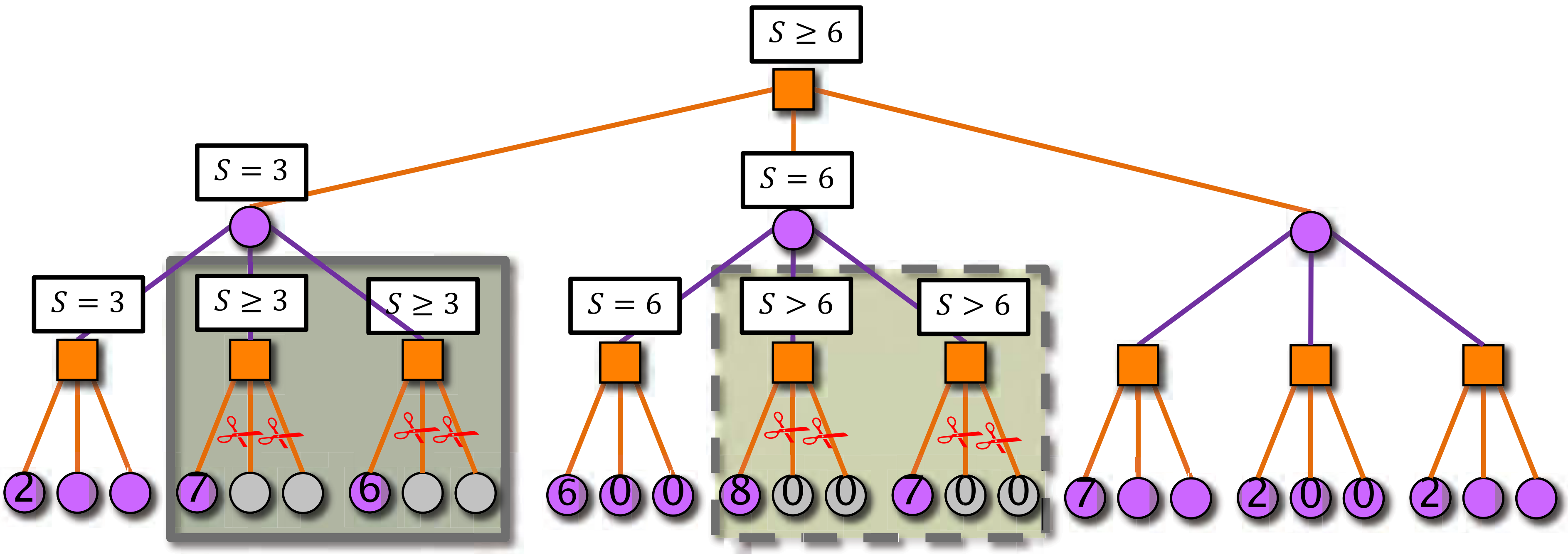
Subtrees executed with scout search

Principal Variation Search Pruning

Fail-Good: Zero-window search says the move might be better. Must do a full window search.

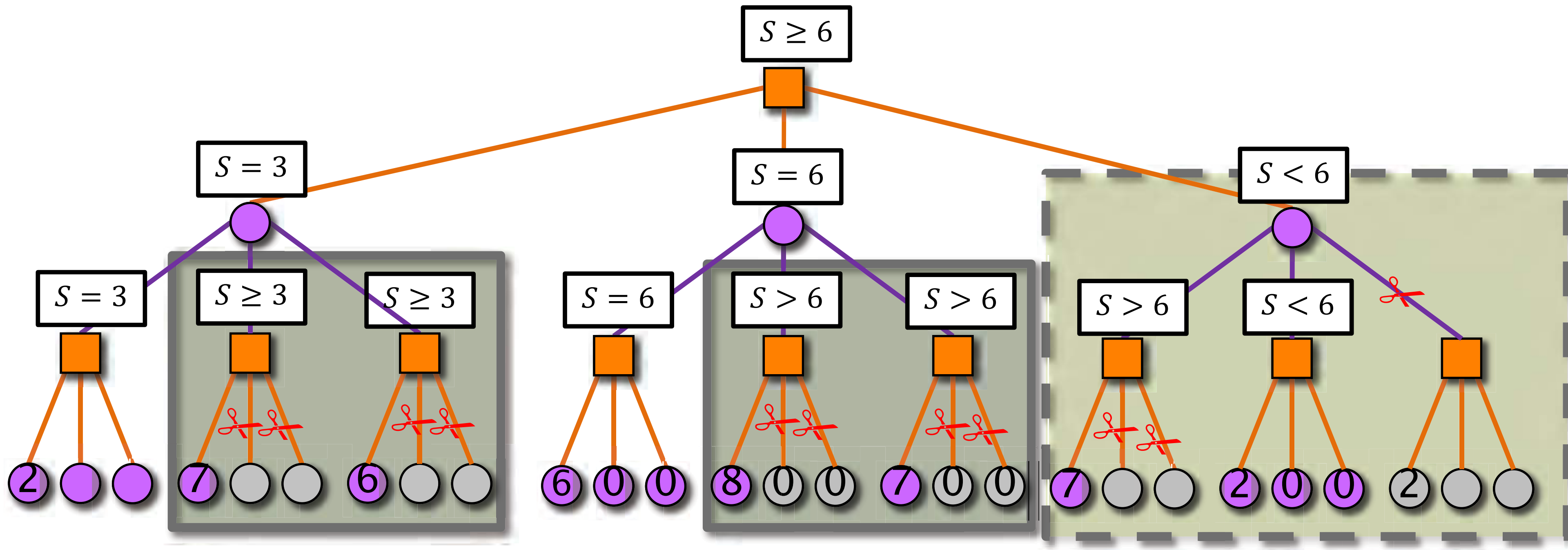


Principal Variation Search Pruning



Subtrees executed with scout search

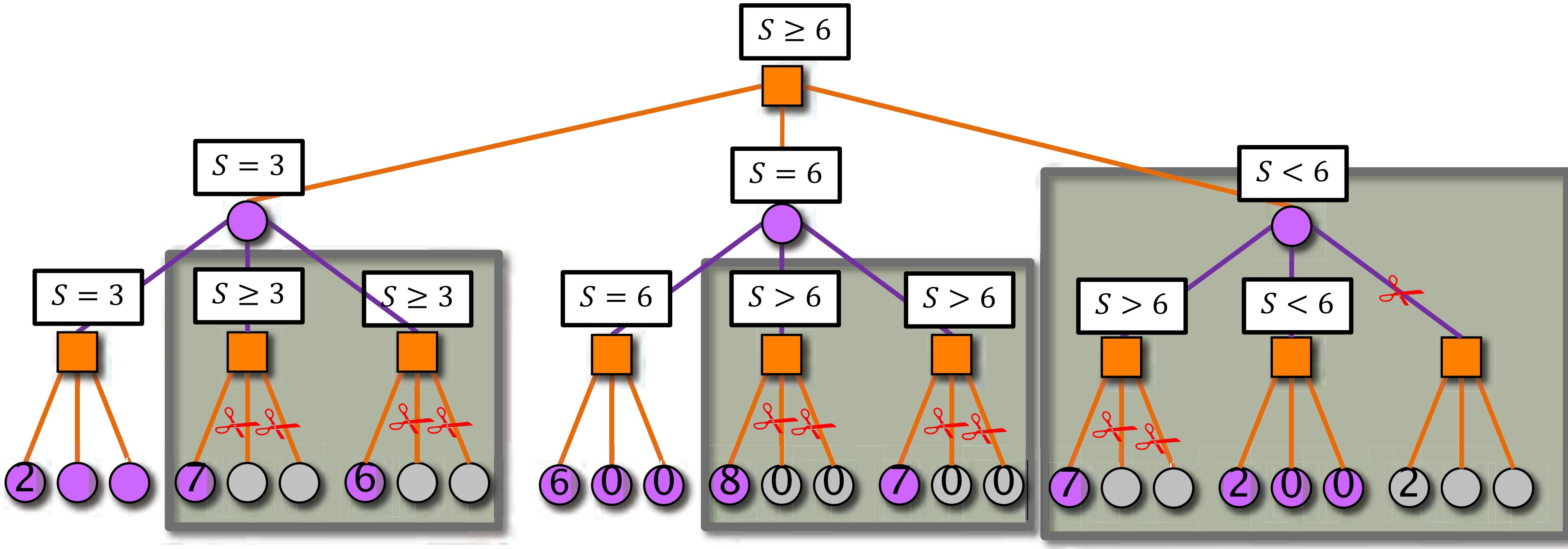
Principal Variation Search Pruning



Subtrees executed with scout search

Principal Variation Search Pruning

Scout search can improve pruning (modestly). Notice that most of the game-tree was processed using only zero-window searches…



13 Leaves Pruned

Subtrees executed with scout search

SEARCH OPTIMIZATIONS

Transposition Table

Chess programs often encounter the same positions repeatedly during their search.

A transposition table stores results of previous searches in a hash table to avoid unnecessary work.

- Call to update: `search.c:195`.
- Update function: `search_globals.c:56`.
- Used to order moves in `search.c:105`.

https://www.chessprogramming.org/Transposition_Table

Zobrist Hashing

Zobrist hashing is a rolling hashing technique to convert a board position into a number of fixed length with uniform probability over all possible numbers (`move_gen.c:112`).

The transposition table uses Zobrist hashing to index into it.

Note: If you change the piece representation and want to use node counts to debug, you must recompute the zobrist hash from the old piece representation.

https://www.chessprogramming.org/Zobrist_Hashing

Killer Move Table

The killer move table stores moves so good that the opponent would prevent you from going down that path, so you can early exit and avoid exploring that subtree.

The table is indexed by ply, because you tend to see the same moves at the same depth.

- Table at `search_globals.c:11`.
- Set at `search_common.c:378`.
- Used in `search_common.c:409`.

https://www.chessprogramming.org/Killer_Heuristic

Best-Move Table

The best move is stored at the root of a search and is the move that gained the maximum score.

The best-move table is indexed by color, piece, square, and orientation.

- Best-move history table at `search_globals:17`.
- Updated at `search_common:367`.

https://www.chessprogramming.org/Best_Move

Null–Move Pruning

Null–move pruning first tries to reduce the search space by not moving and then doing a shallower search to see if the subtree can still cause a beta cutoff.

If the tree can cause a beta cutoff even without a move, it is too good. The opponent would not let us go there, and so the search does not bother to explore it.

- Implemented at `search_common.c:193`.

https://www.chessprogramming.org/Enhanced_Forward_Pruning
https://www.chessprogramming.org/Null_Move_Pruning

Futility Pruning

Futility pruning only explores moves that have the potential to increase `alpha`.

It calculates this possibility by adding a futility margin (the largest possible gain) to the evaluation of the current position.

If the result does not exceed `alpha`, skip the search of this move.

- Implemented at `search_common.c:209`.

https://www.chessprogramming.org/Futility_Pruning

Late-Move Reduction

After ordering the moves from a position, the moves at the front of the list are more likely to cause a cutoff.

Late-move reduction searches the first few (3 or 4) moves to full depth and the remaining ones with less depth.

- Implemented in scout search at `search_common.c:289`.

https://www.chessprogramming.org/Late_Move_Reductions

Opening Book

Opening books store positions at the beginning of the game.

Idea: Precompute the best moves at the beginning of the game.

They save time in searching and can store results to a higher depth.

The [KM75] theorem implies it is cheaper to keep separate opening books for each side than one opening book for both.

https://www.chessprogramming.org/Opening_Book

Endgame Database

An endgame database is a table for guiding a chess program through the endgame.

For endgame positions, the distance from the end might be too far to search. With an endgame database, you can store who will win and how far you are from the end of the game.

`player/end_game.c` is a great place to store an endgame database.

https://www.chessprogramming.org/Endgame

Tips And Tricks

Chess Programming

- The Chess Programming wiki (https://www.chessprogramming.org) is an invaluable resource for learning about the parts of a chess-playing program.

https://www.chessprogramming.org

General Guidelines

- Test often! It is easy to make a mistake with your optimizations that does not appear when you just search to fixed depth.
- Testing methodology
  - WebGUI
  - Java Autotester
  - Cloud Autotester
  - Node counts
  - Function comparison testing

Optimization Tips

- Start with optimizations that do not affect the search (e.g. modifying the board representation).
- Improve the existing heuristics before trying to come up with your own.
- There are plenty of serial optimizations that you can make before thinking about parallelization.