Battleship Complexity

GT GDMM 2021

March 16th 2021, Nancy, France

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Joined work with Loïc Crombez and Guilherme Da Fonseca

UNIVERSITÉ Clermont Auvergne

LIMOS

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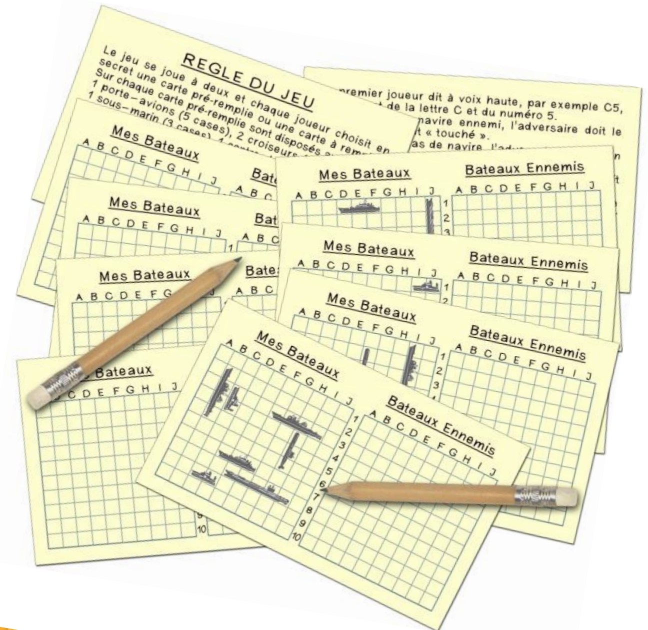
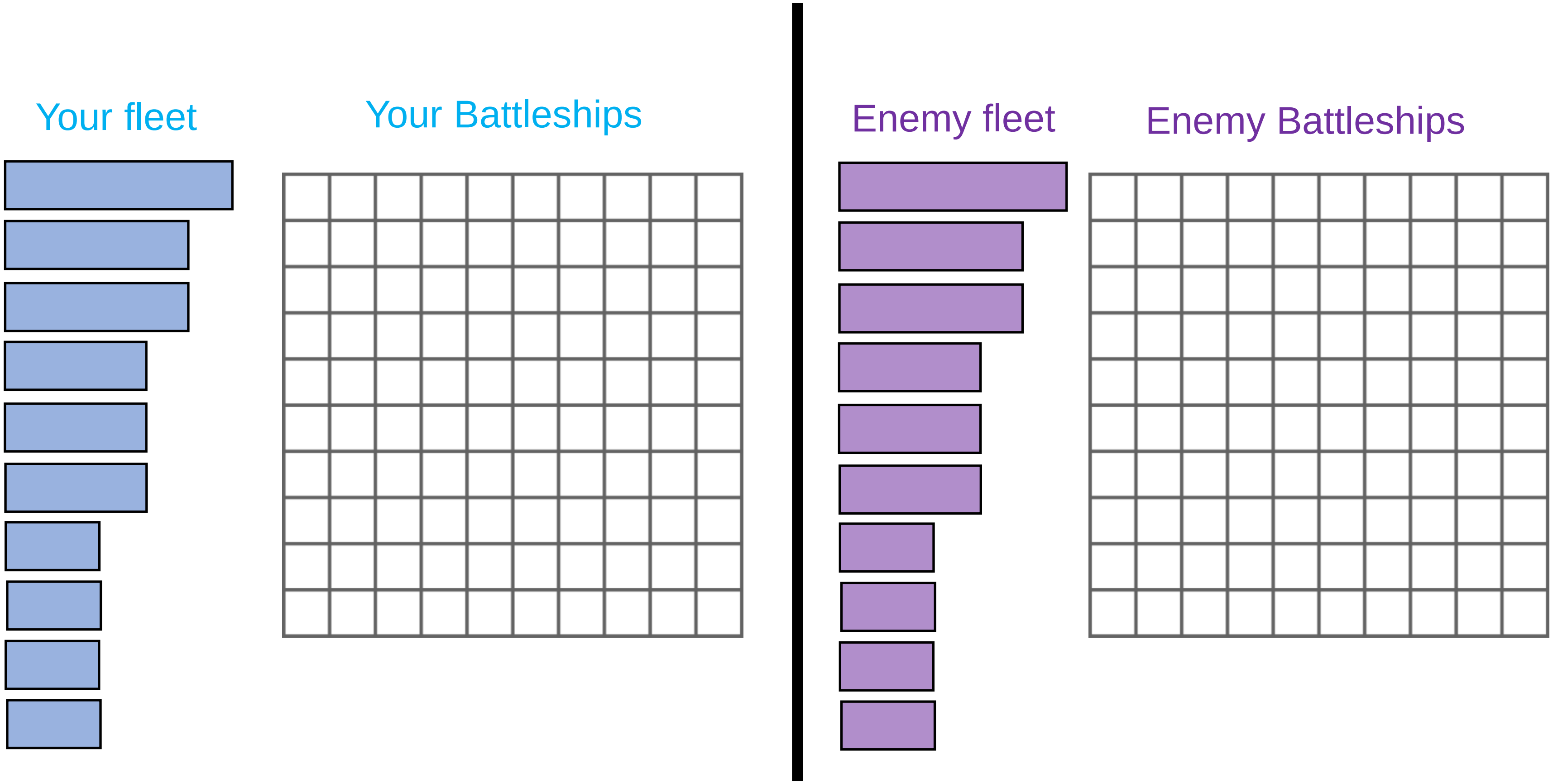
1 Problem statement

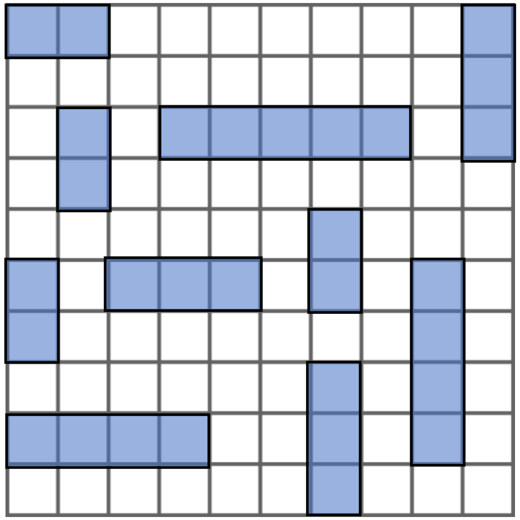
The game



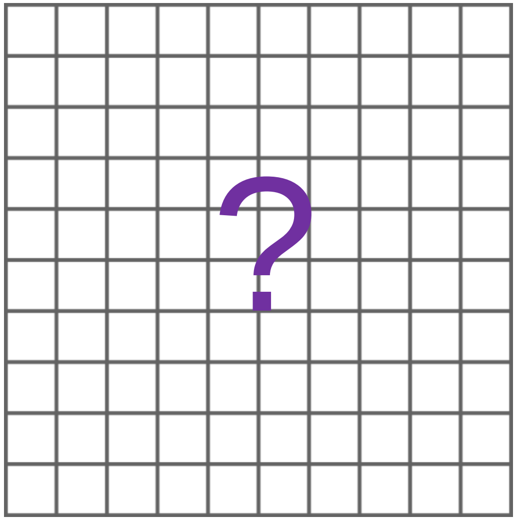


2 players : you and the enemy

Your Battleships



Enemy Battleships



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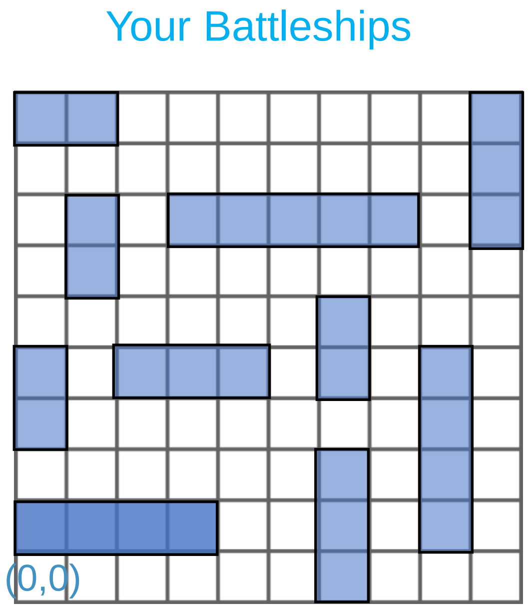
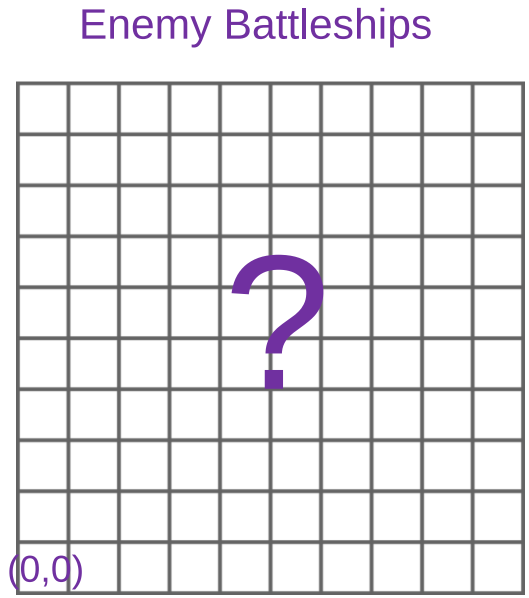
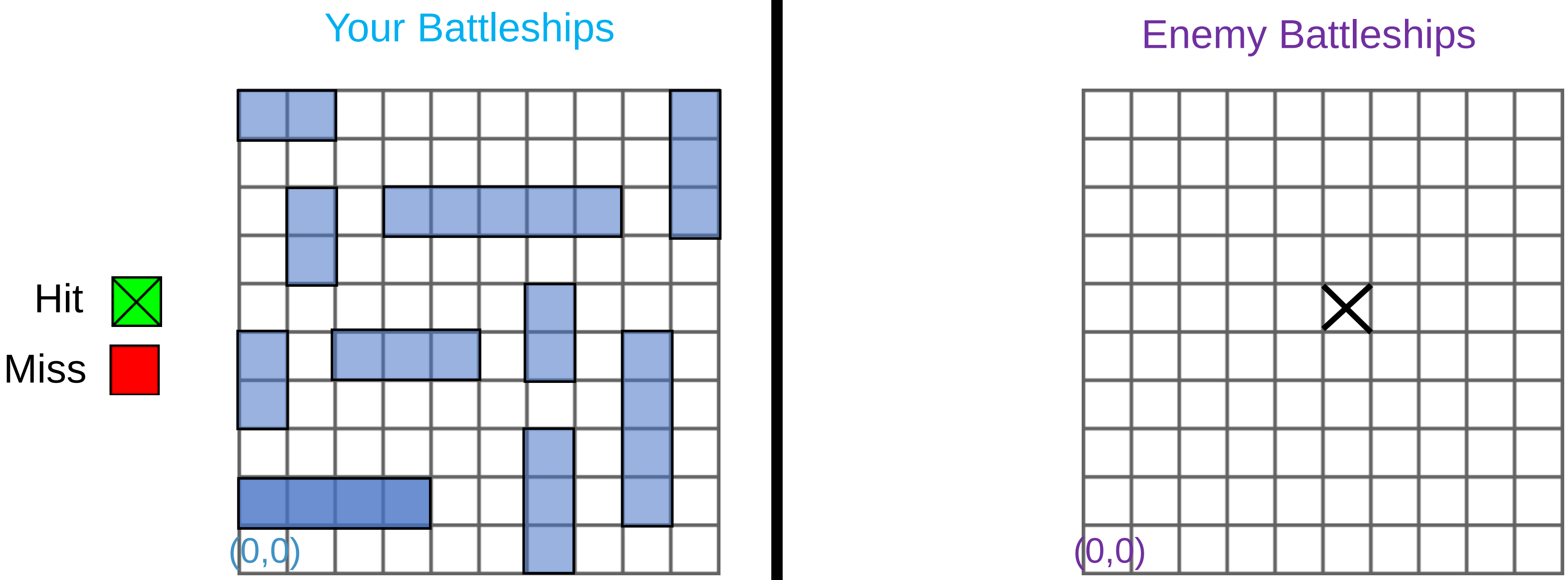




At each turn, shoot a square in your enemy grid => the enemy tells you if it is a hit or a miss



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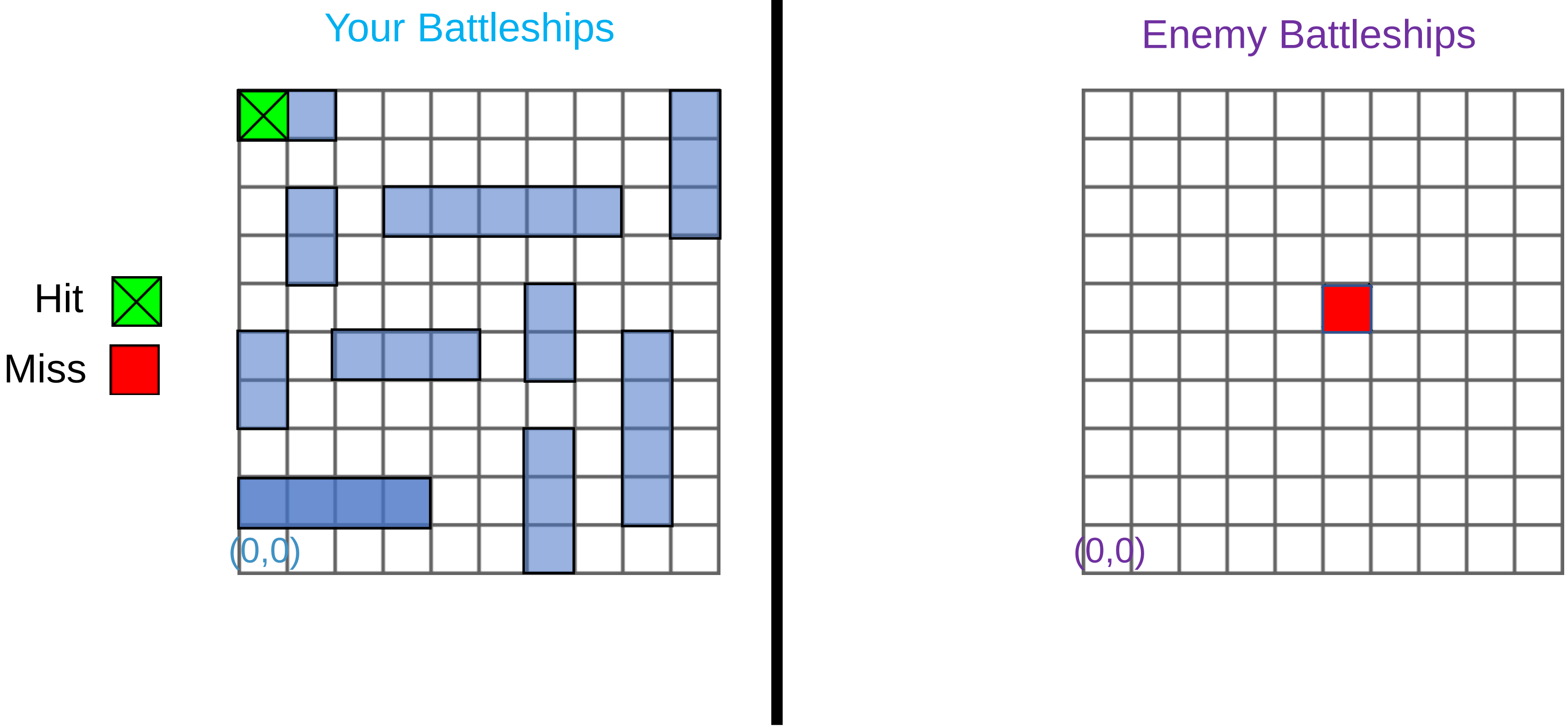

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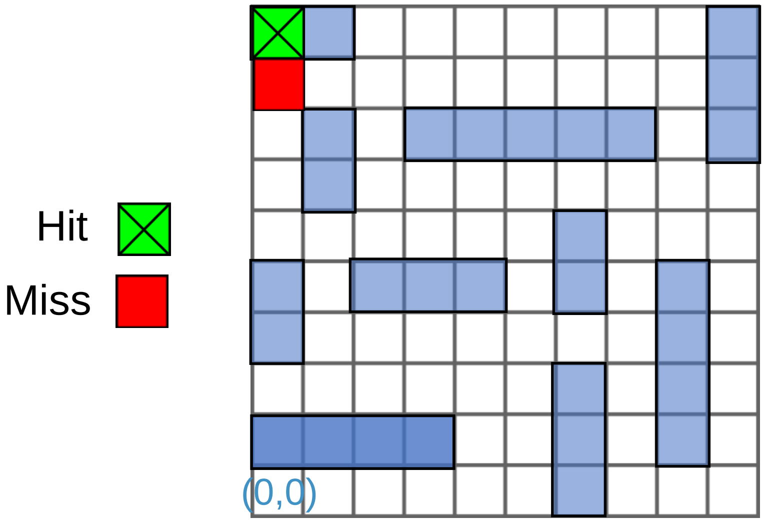

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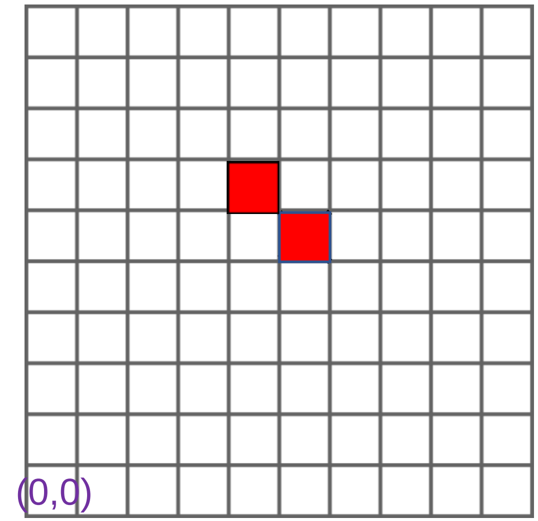

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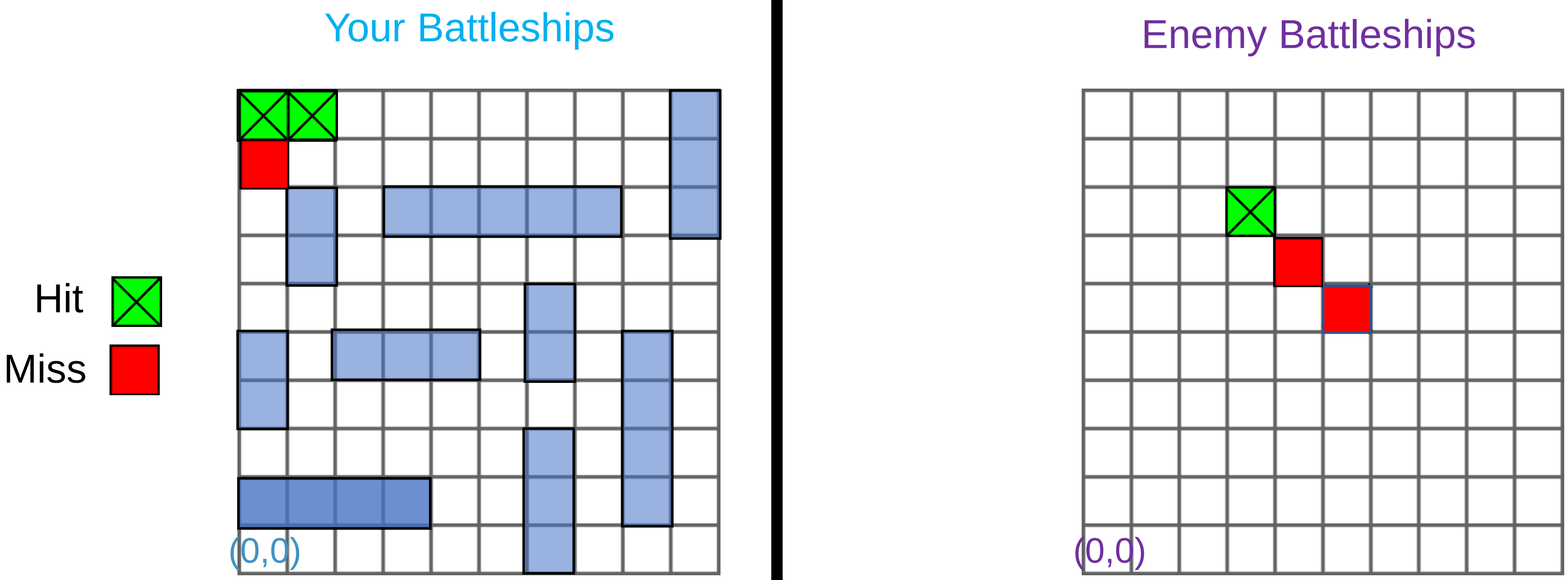

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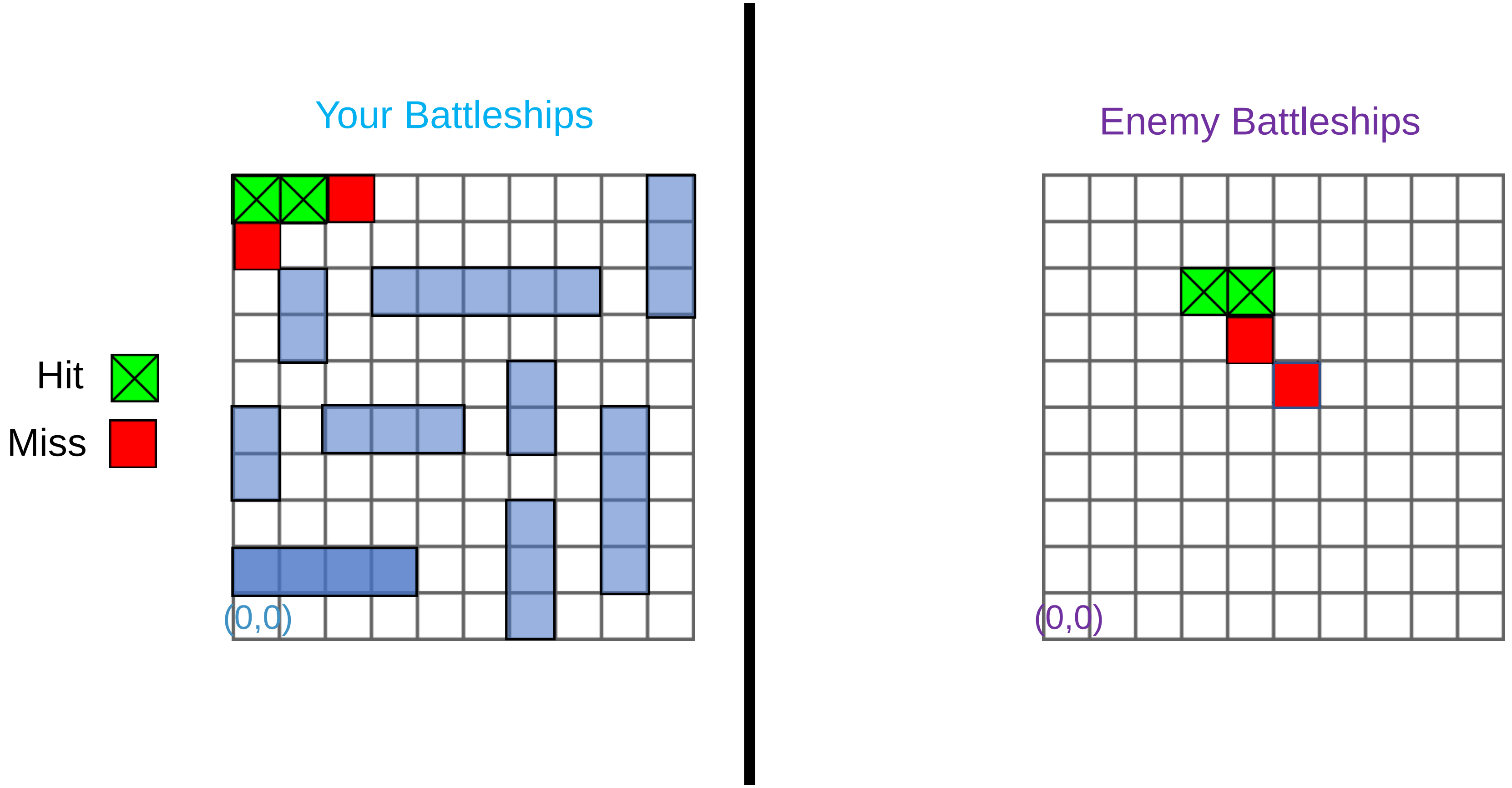

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Your Battleships

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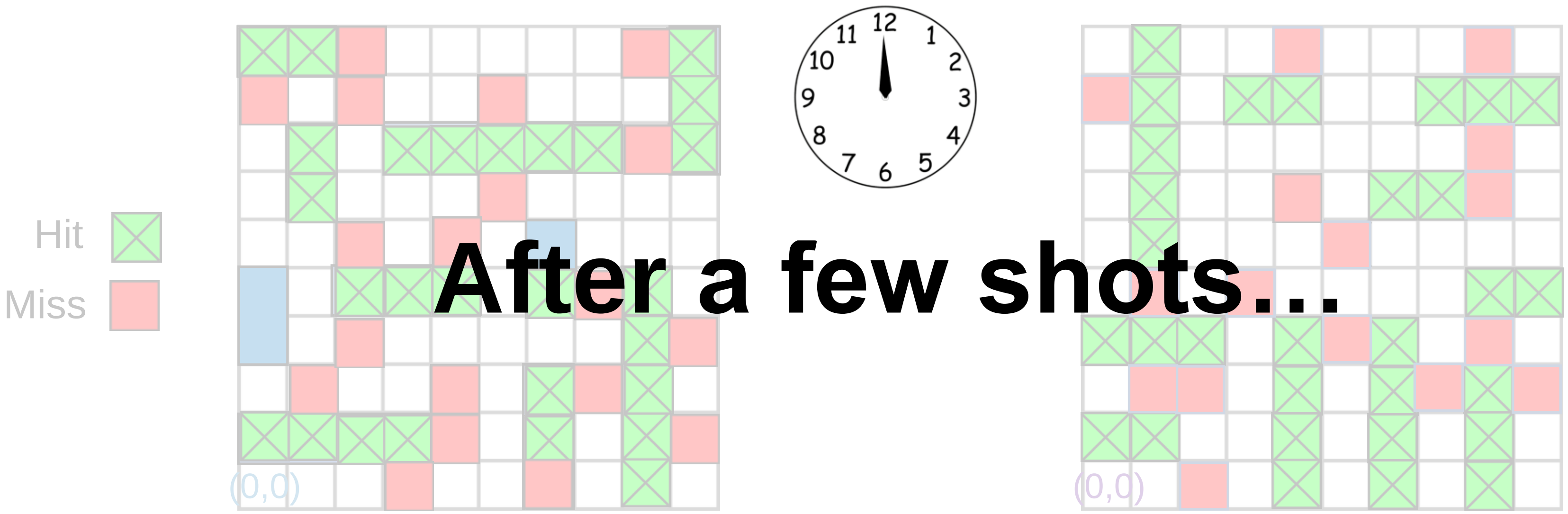
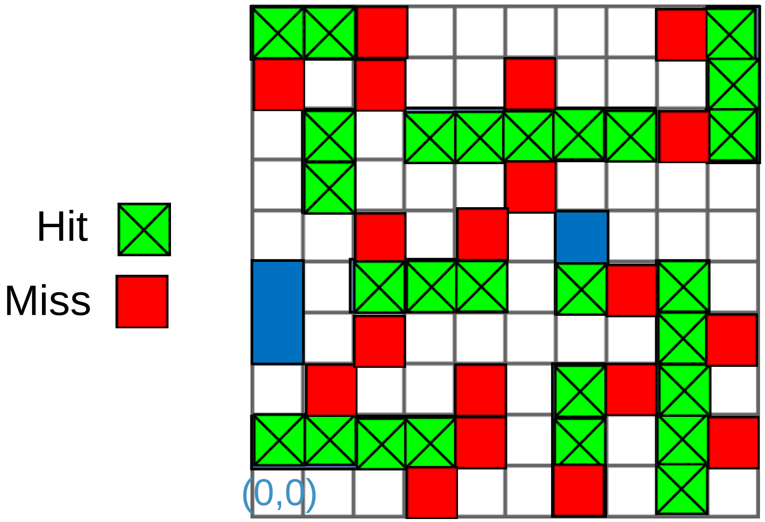


You still have safe squares

All enemy ships have been sunk

At each turn, shoot a square in your enemy grid => the enemy tells you if it is a hit or a miss

Your Battleships



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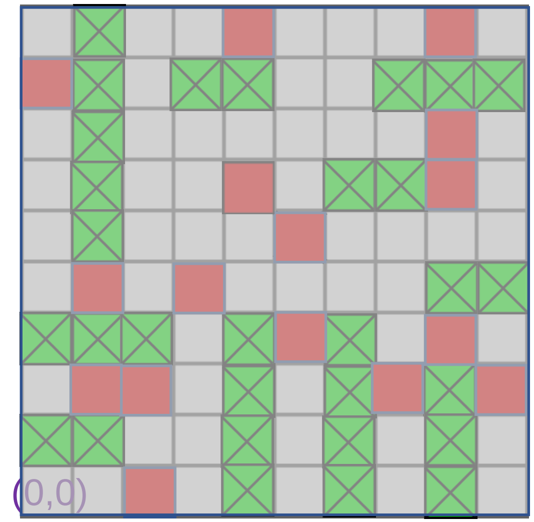

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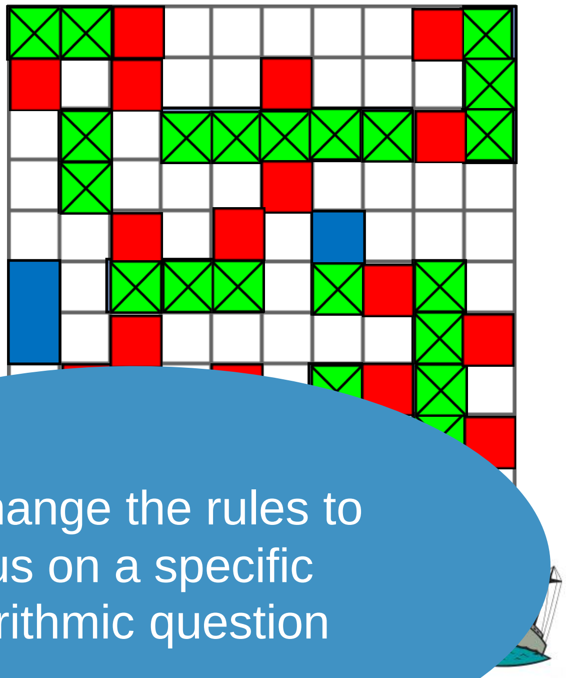
The winner is the first player which has hit all the squares of the enemy fleet

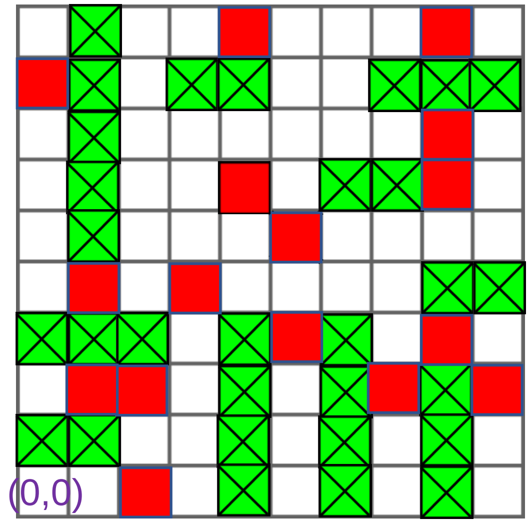
Your Battleships



Hit

Miss

Enemy Battleships



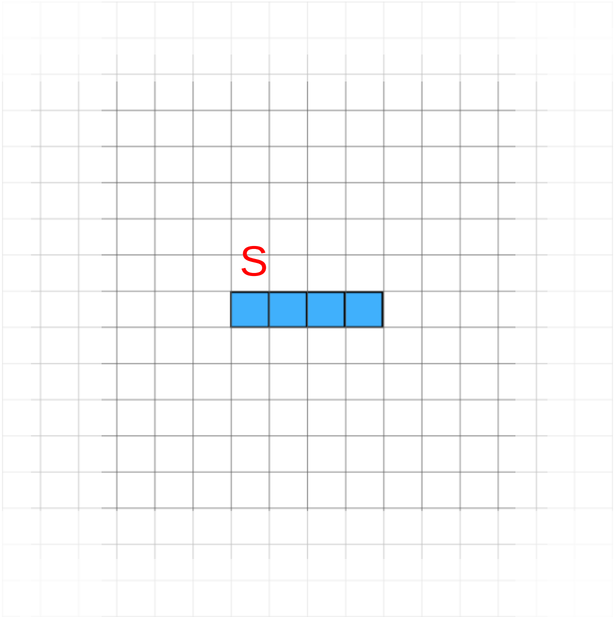
All enemy ships have been sunk

We change the rules to focus on a specific algorithmic question

At each turn, shoot a square in your enemy grid => the enemy tells you if it is a hit or a miss

The winner is the first player which has hit all the squares of the enemy's fleet

- Only one ship S in an unbounded grid (no information comes from a position close to the boundary of the grid)



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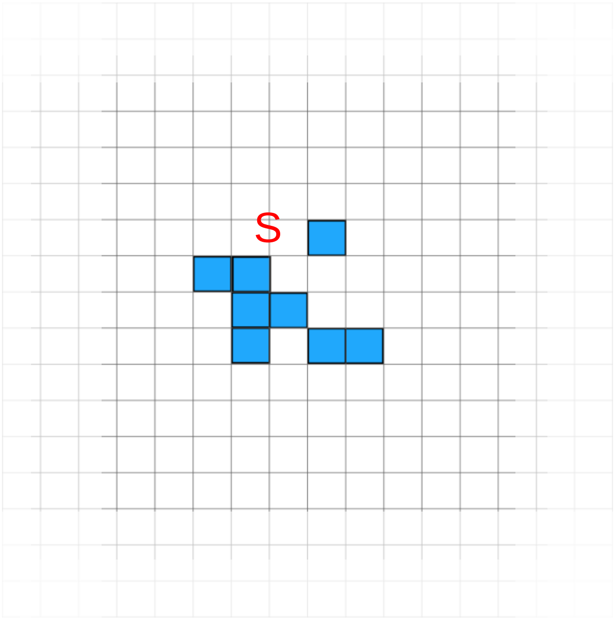
- The shape of the ship is given but there is no restriction on it…



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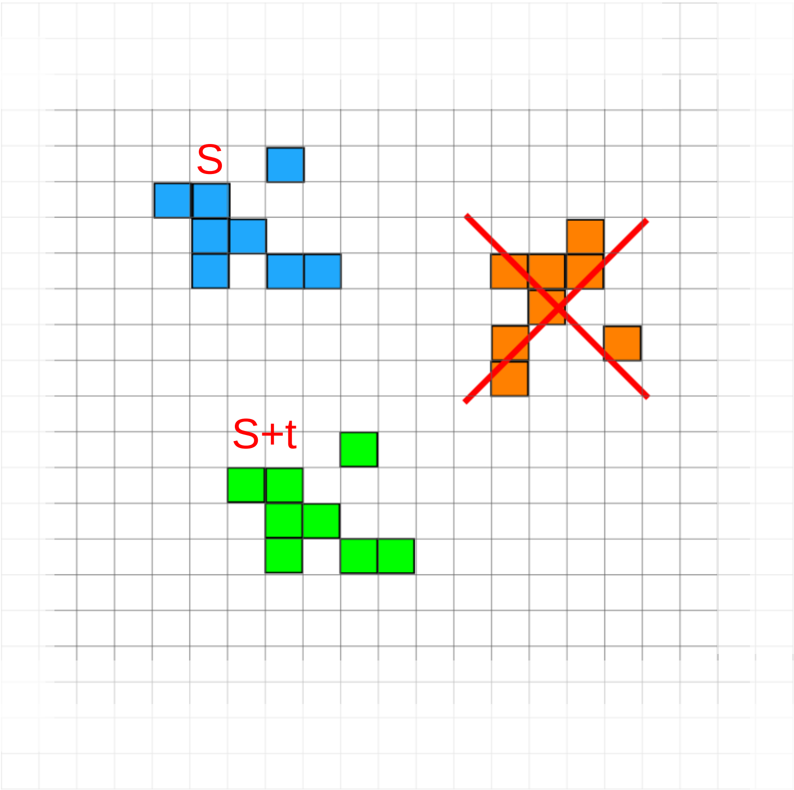

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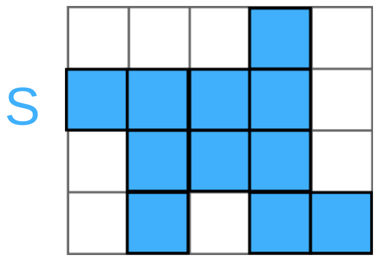
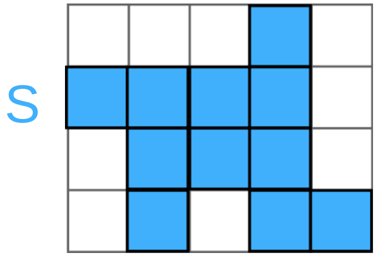


Shape of the ship



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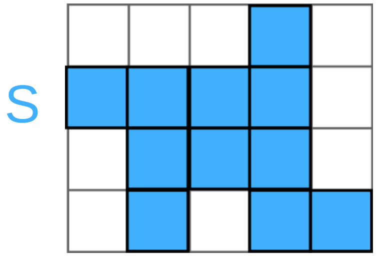
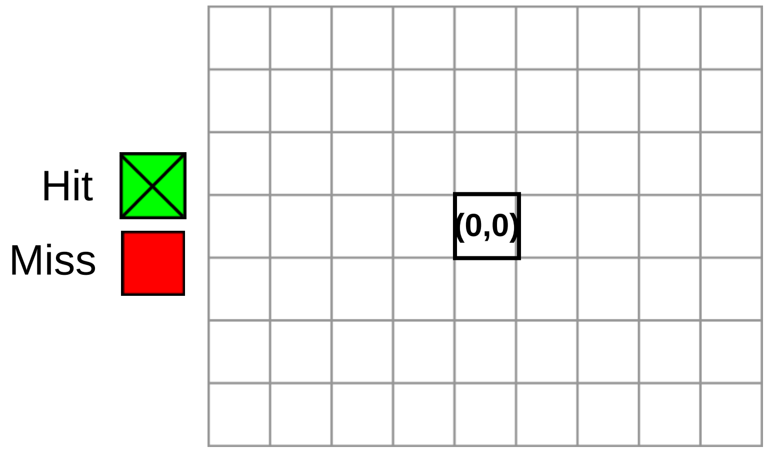
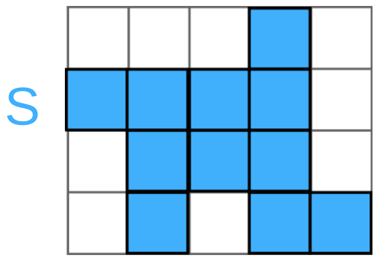


Shape of the ship

n=|S|=11



Shooting grid



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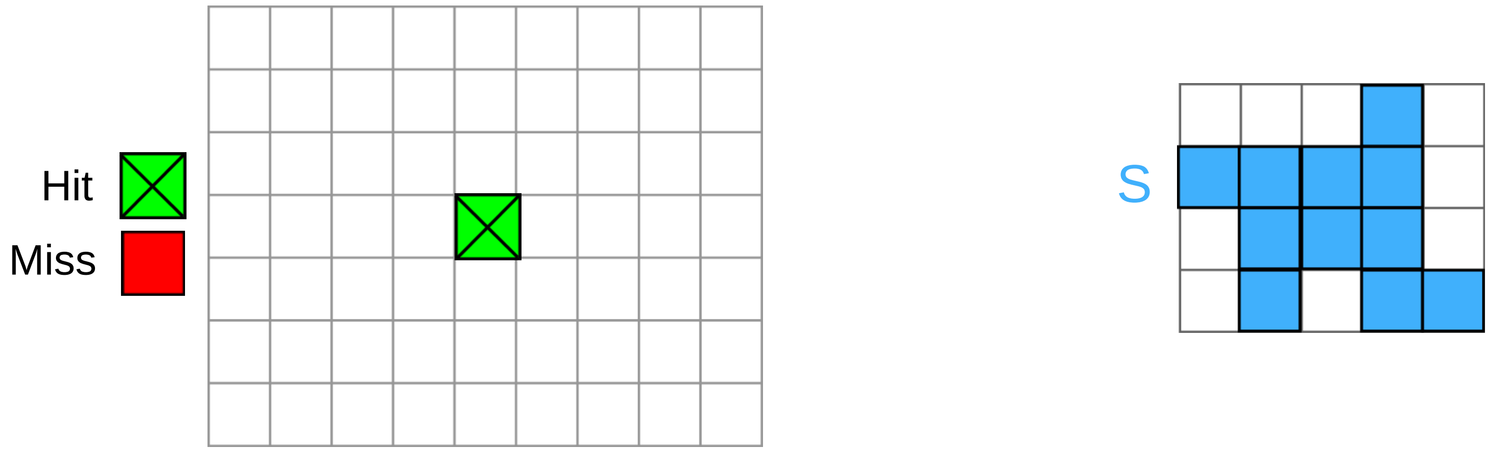
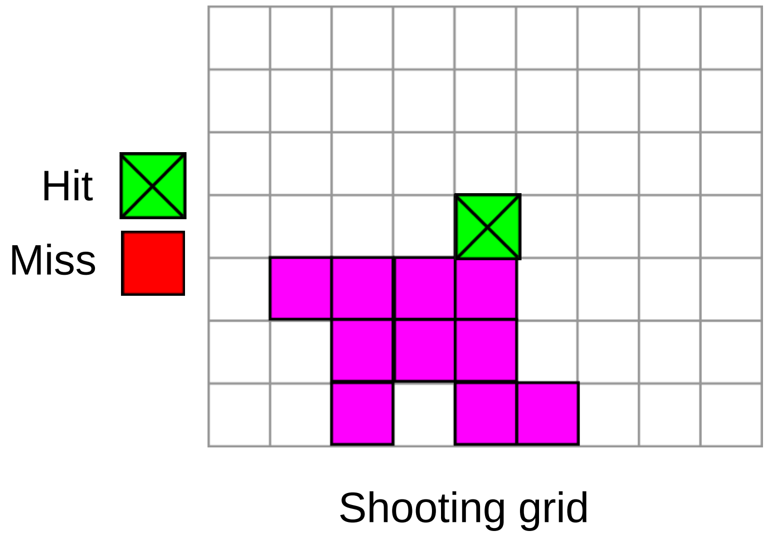
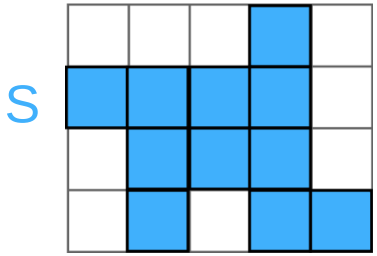


Shooting grid

We assume that the ship has been hit one time by shooting at coordinates (0,0)





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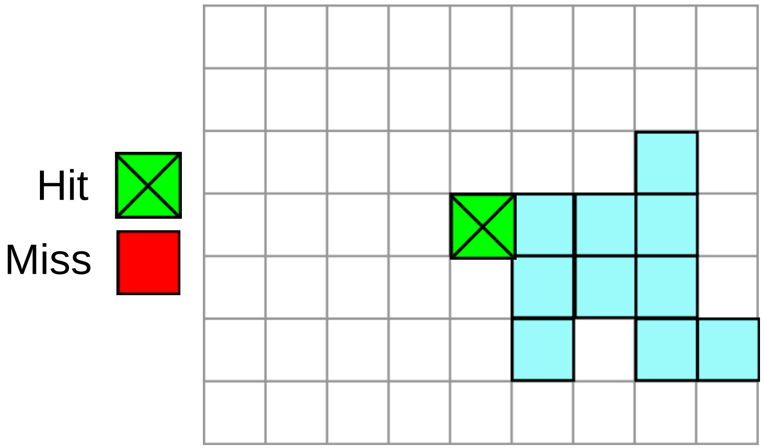

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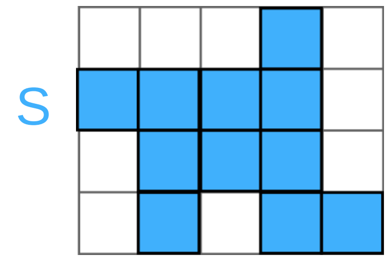

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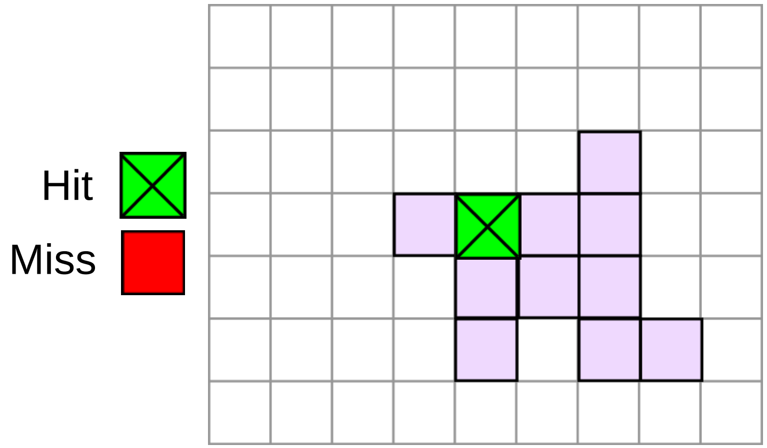

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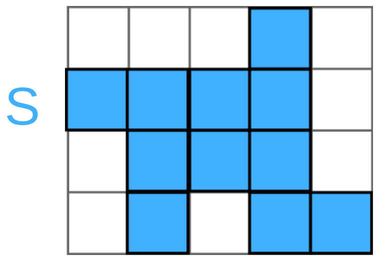

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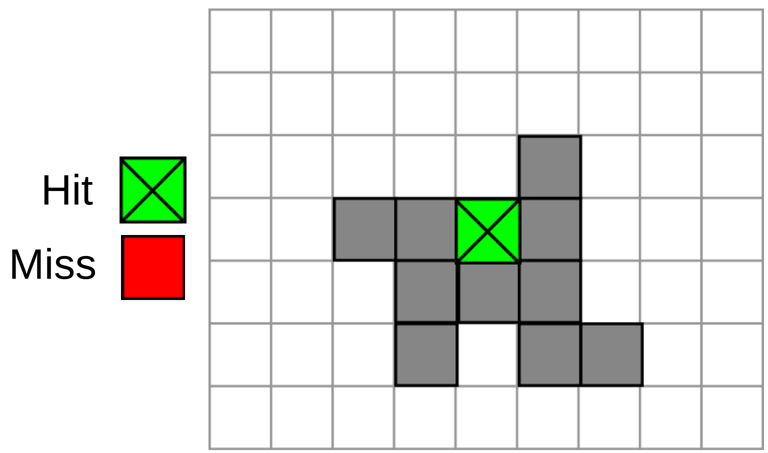

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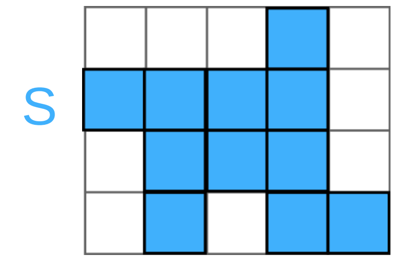

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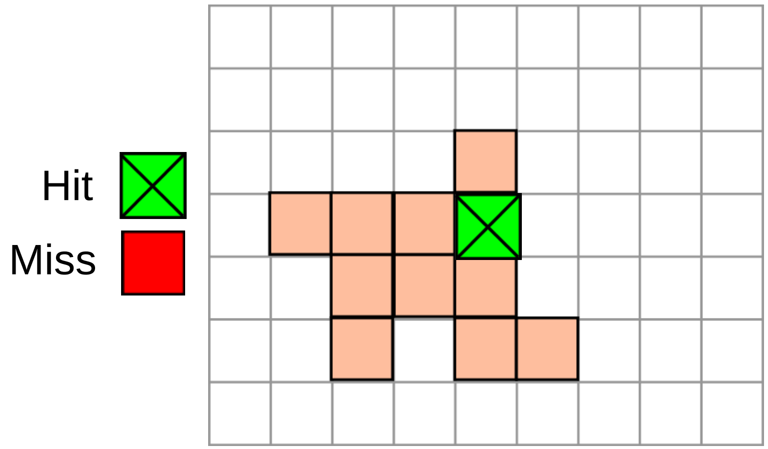

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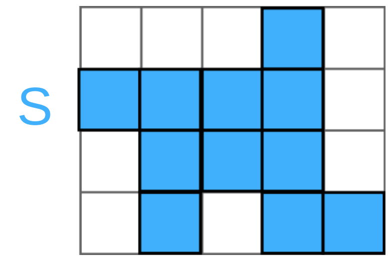

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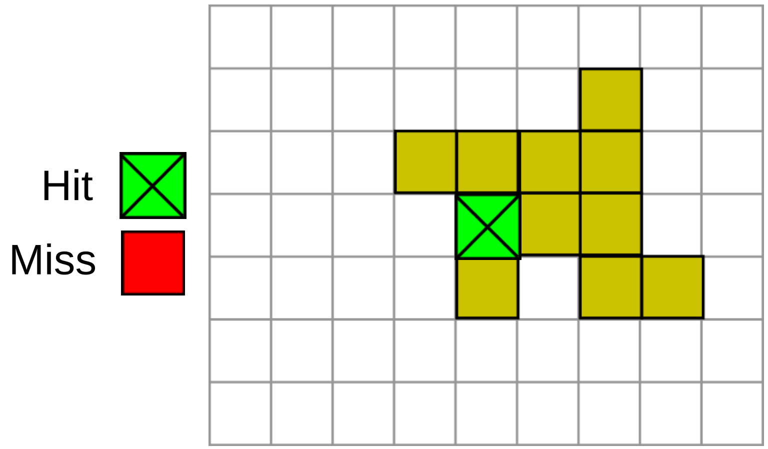

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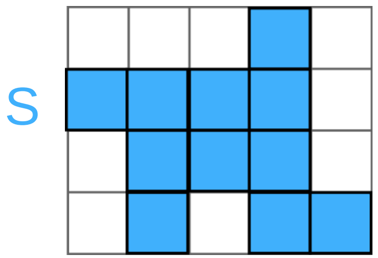

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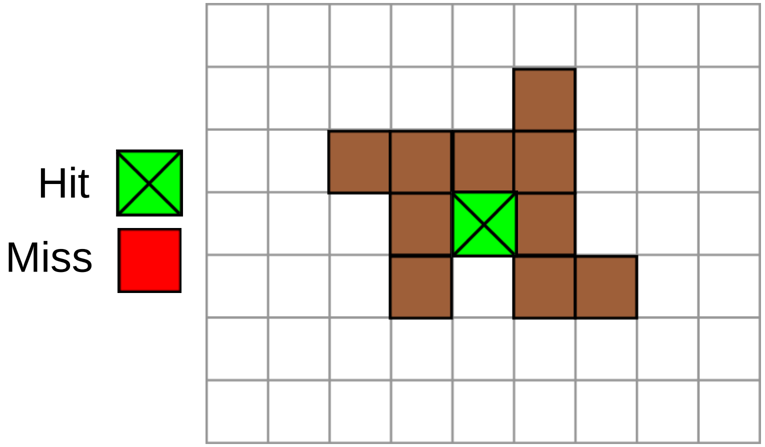

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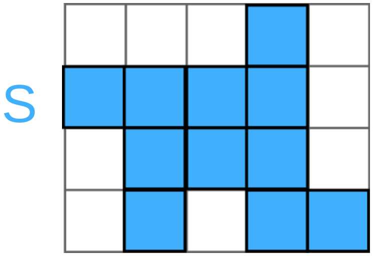

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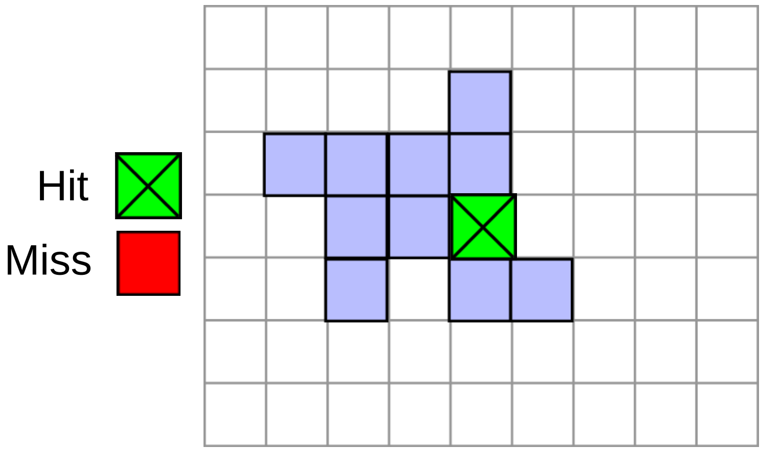

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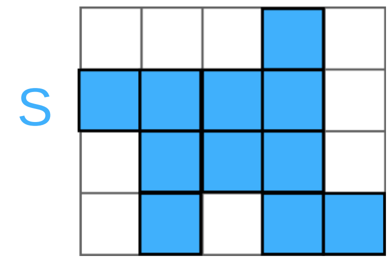

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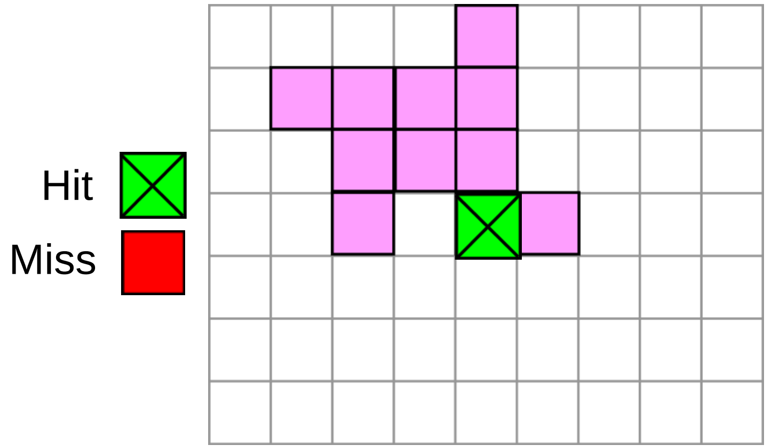

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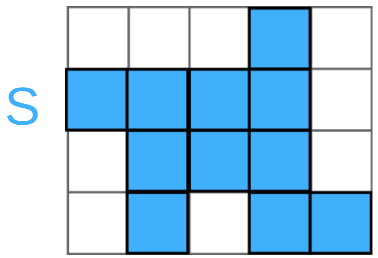

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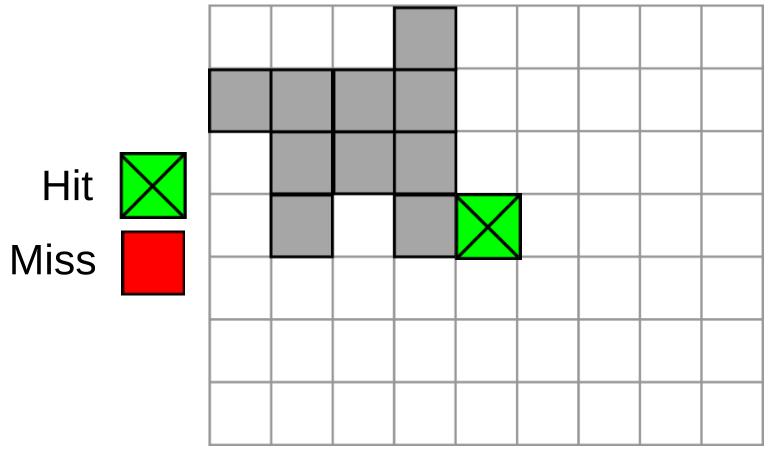

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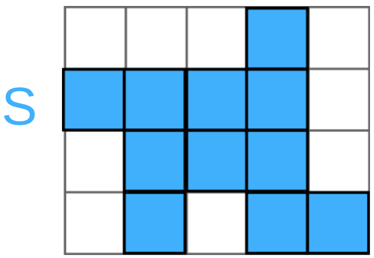

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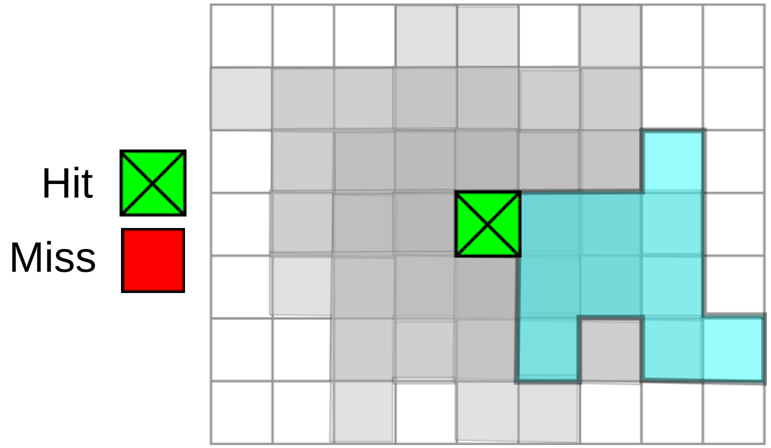
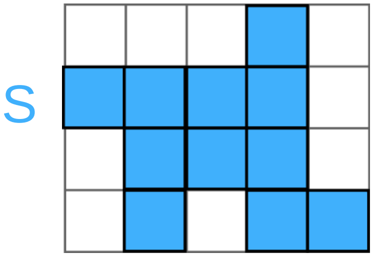


Shooting grid

n positions are possible…



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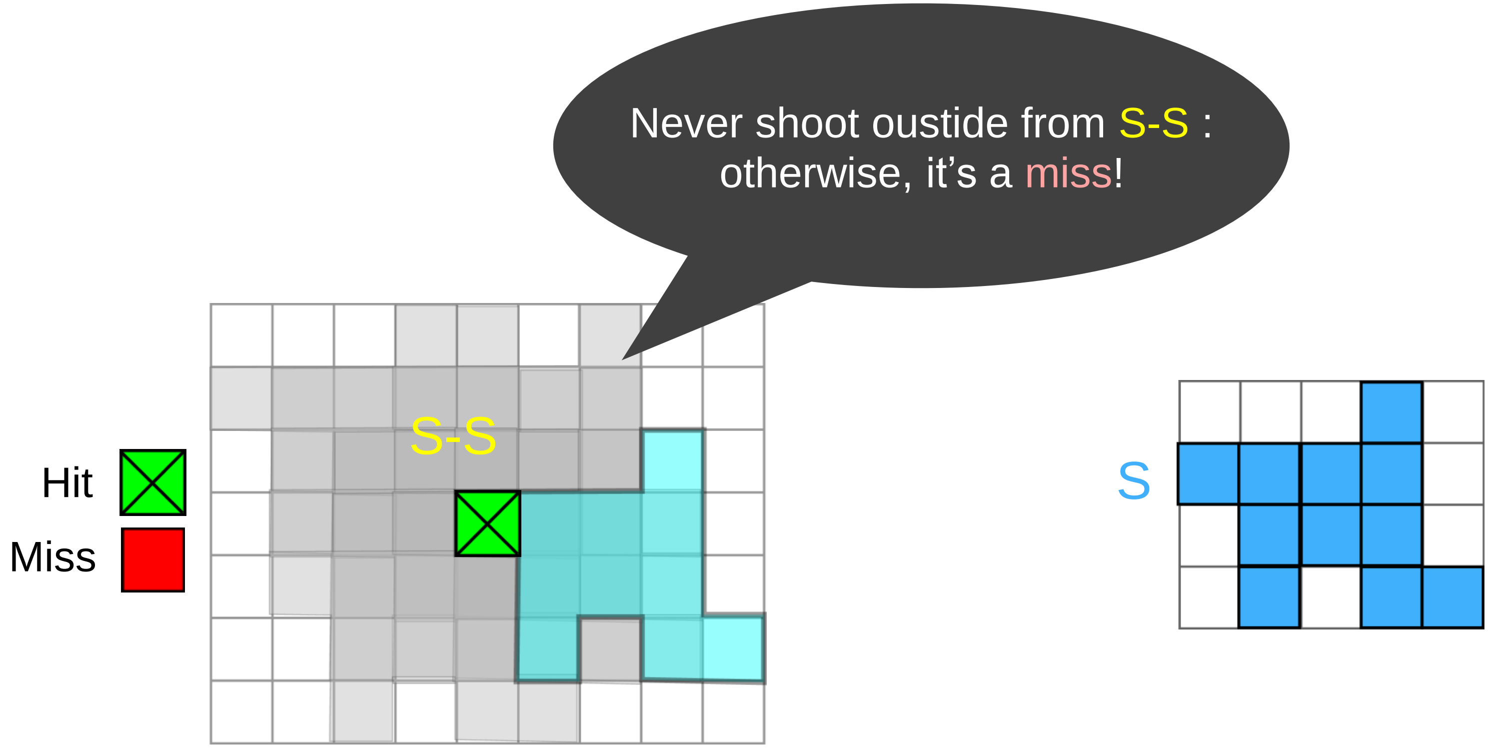

Shooting grid

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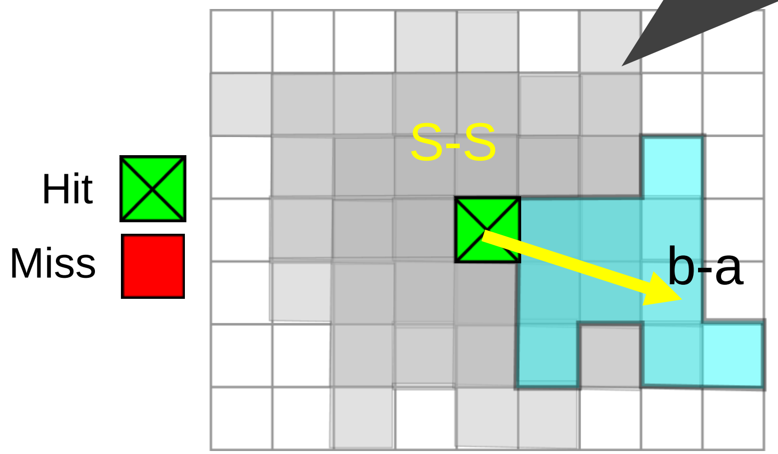
We assume that the ship has been hit one time by shooting at coordinates (0,0)

Never shoot oustide from S-S :
otherwise, it's a miss!



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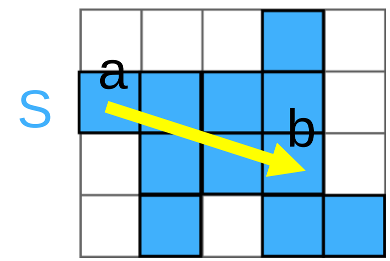

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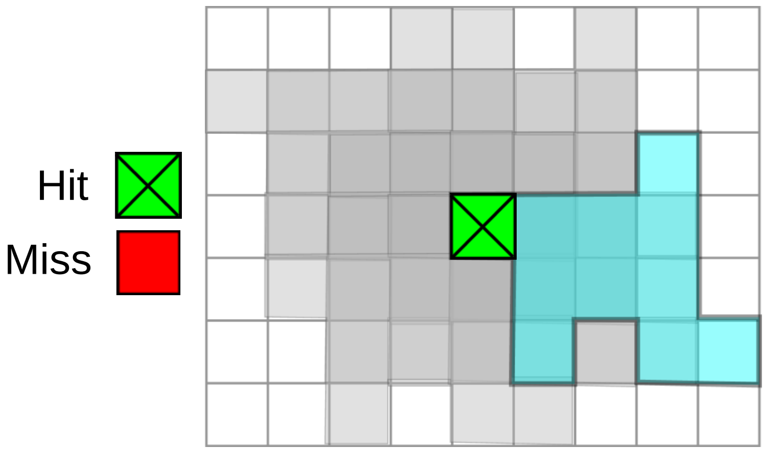

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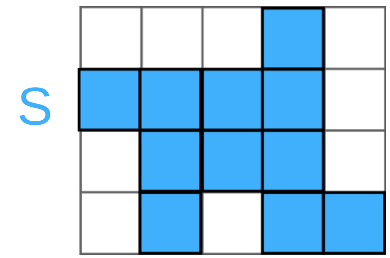

Now, the goal is :
sink the ship with the fewer number of shots as possible

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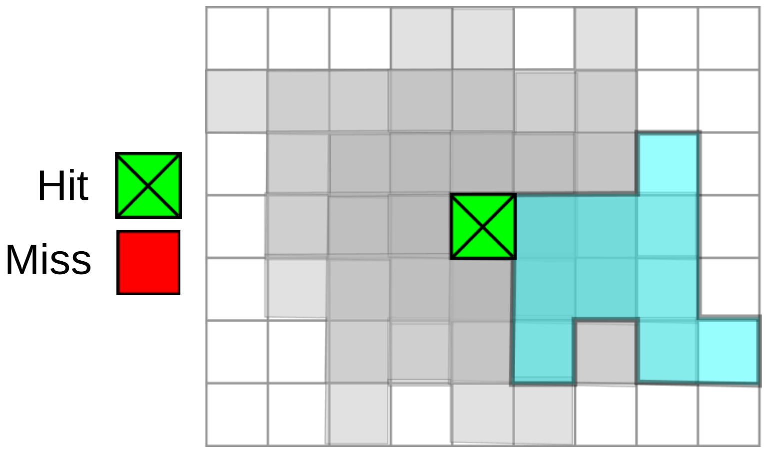

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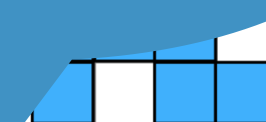

translation:
sink the ship with the fewer number of misses as possible

Now, the goal is :
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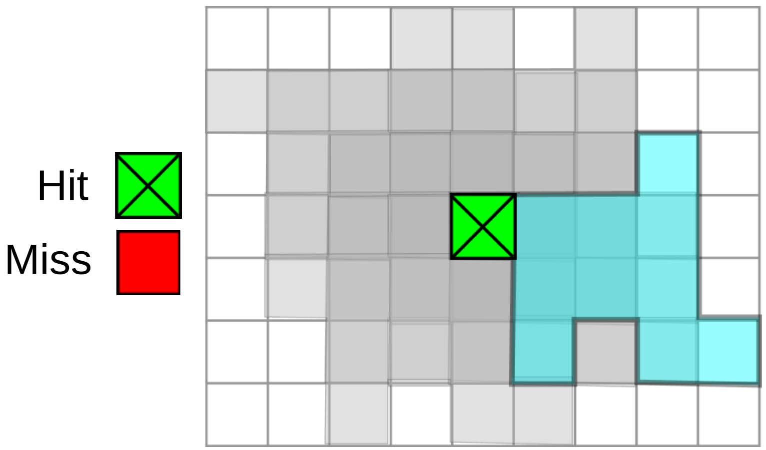
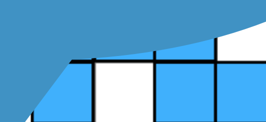
We assume that the ship has been hit one time by shooting at coordinates (0,0)

Find the position of the ship with the fewer number of misses as possible

translation:
sink the ship with the fewer number of misses as possible





Shooting grid

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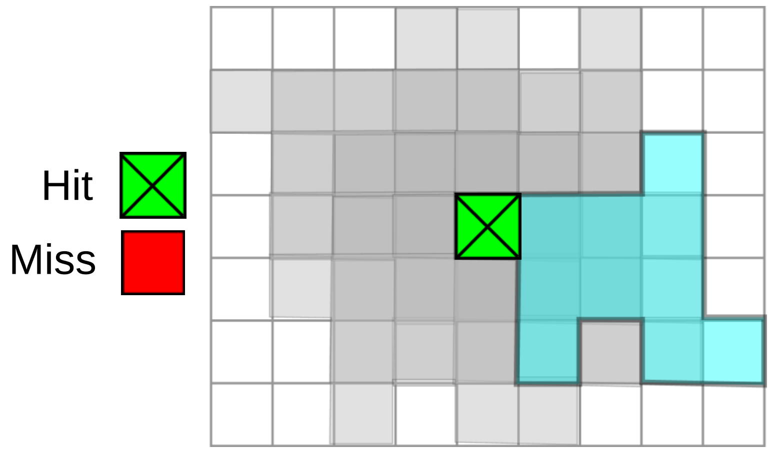
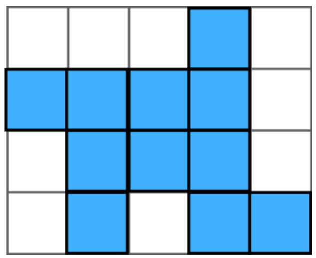


Shooting grid

n positions are possible…

S



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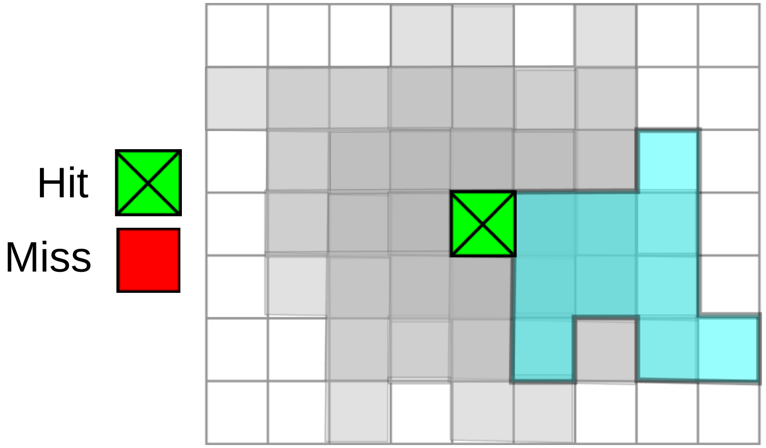
Find the position of the ship with the fewer number of misses as possible



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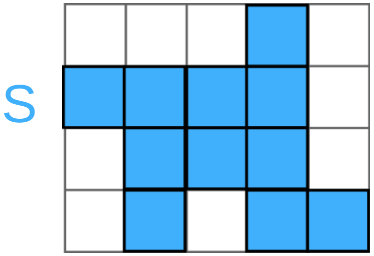
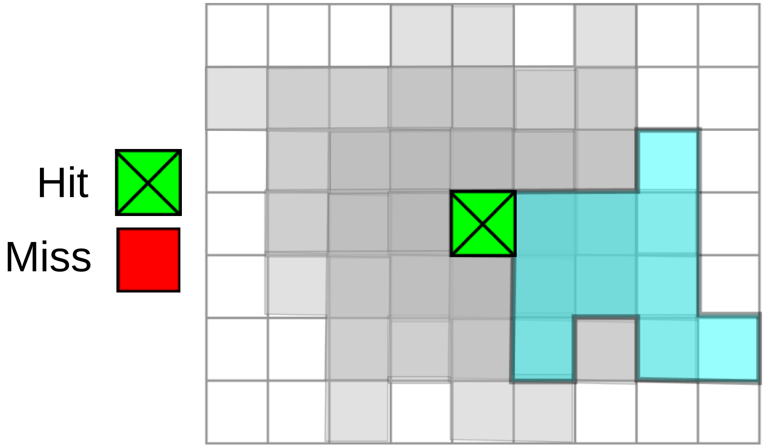


Find the position of the ship with the fewer number of misses as possible



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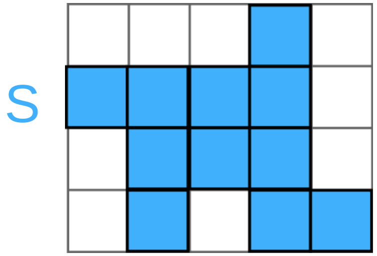

Design a shooting algorithm to find the position of the ship with the fewer number of misses…

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Given a shape, our goal is to design a shooting algorithm
to find the position of the ship
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Shape of the ship

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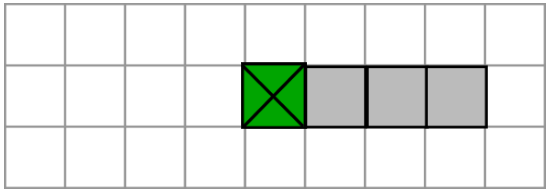

Shooting grid

4 positions are possible…

Shape of the ship

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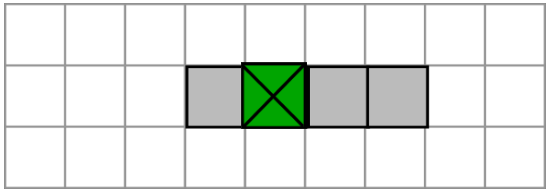

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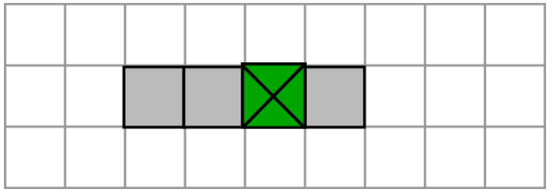

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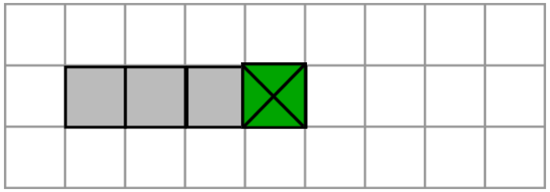

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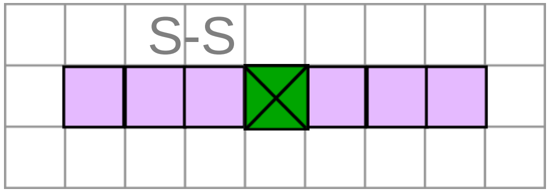

Shooting grid

4 positions are possible…

Shoot (1,0) ?

Shoot (2,0) ?

Shoot (3,0) ?

Shoot (-1,0) ?

Shoot (-2,0) ?

Shoot (-3,0) ?

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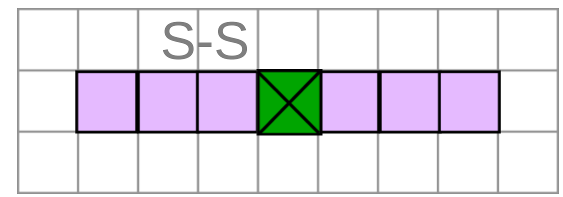


Shooting grid

4 positions are possible…

Choose a new shot

Shoot (1,0) ?

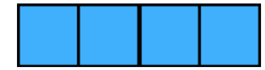
Shoot (2,0) ?

Shoot (3,0) ?

Shoot (-1,0) ?

Shoot (-2,0) ?

Shoot (-3,0) ?



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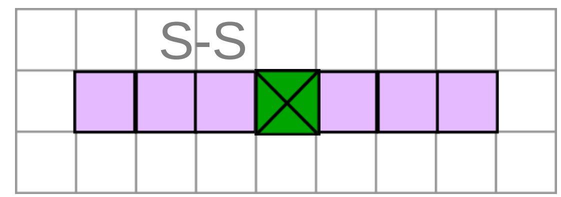

Shooting grid

4 positions are possible…

What is the best strategy ?

Shape of the ship

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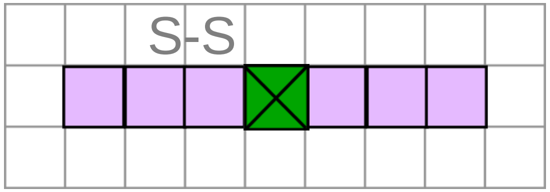

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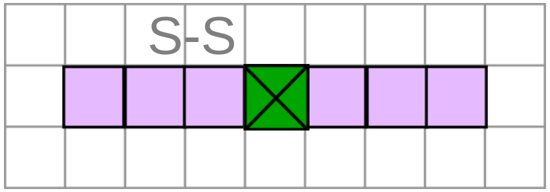

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A shooting algorithm:
Shoot on the left of the previous shot until having a miss.
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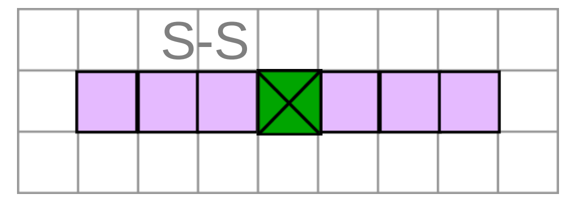

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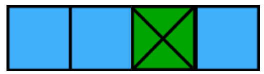

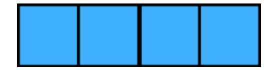

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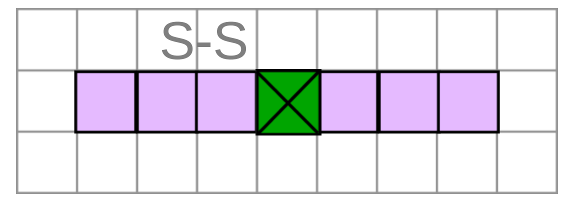

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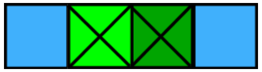

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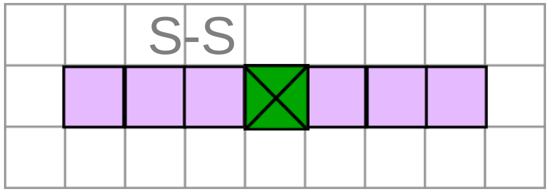

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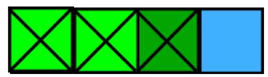

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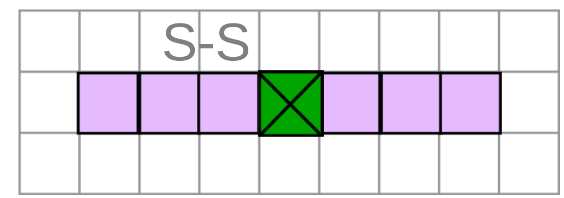

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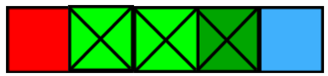

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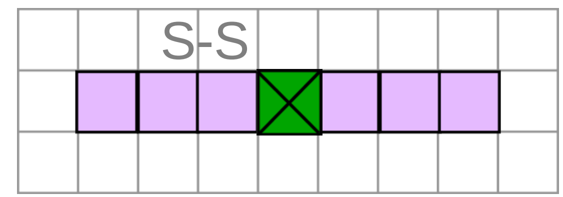

Shooting grid

4 positions are possible…

A shooting algorithm:

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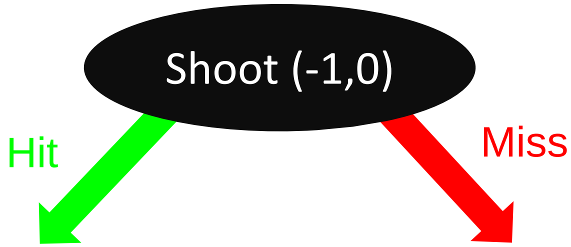
What is the best strategy ?

Shoot (-1,0)

Shape of the ship



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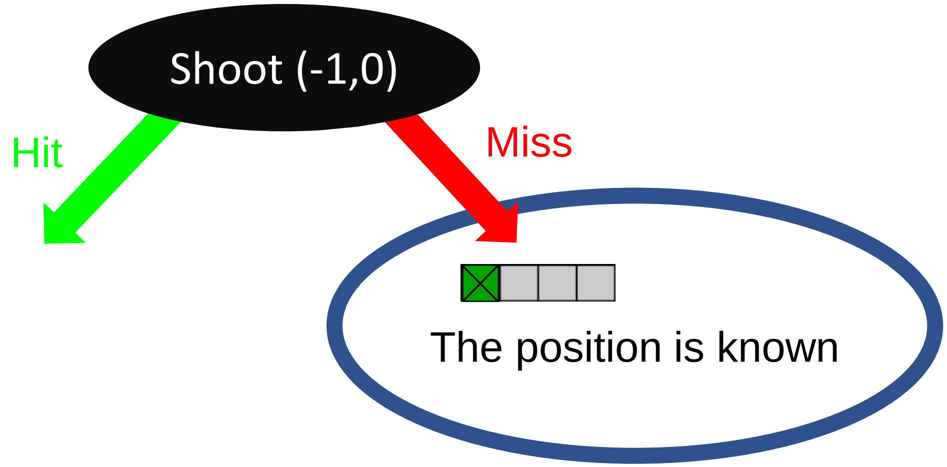
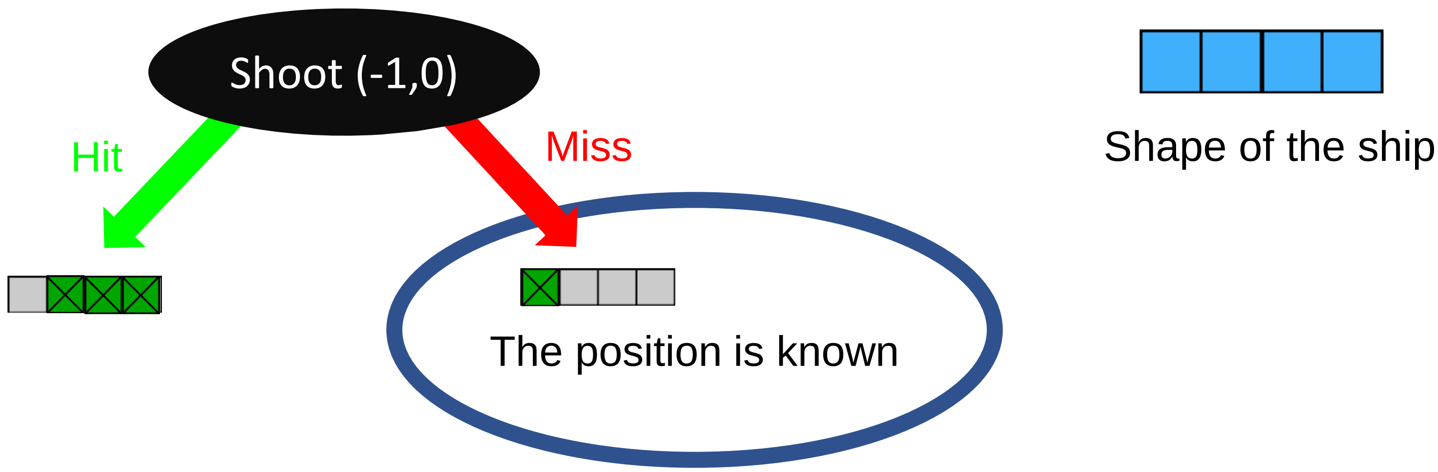
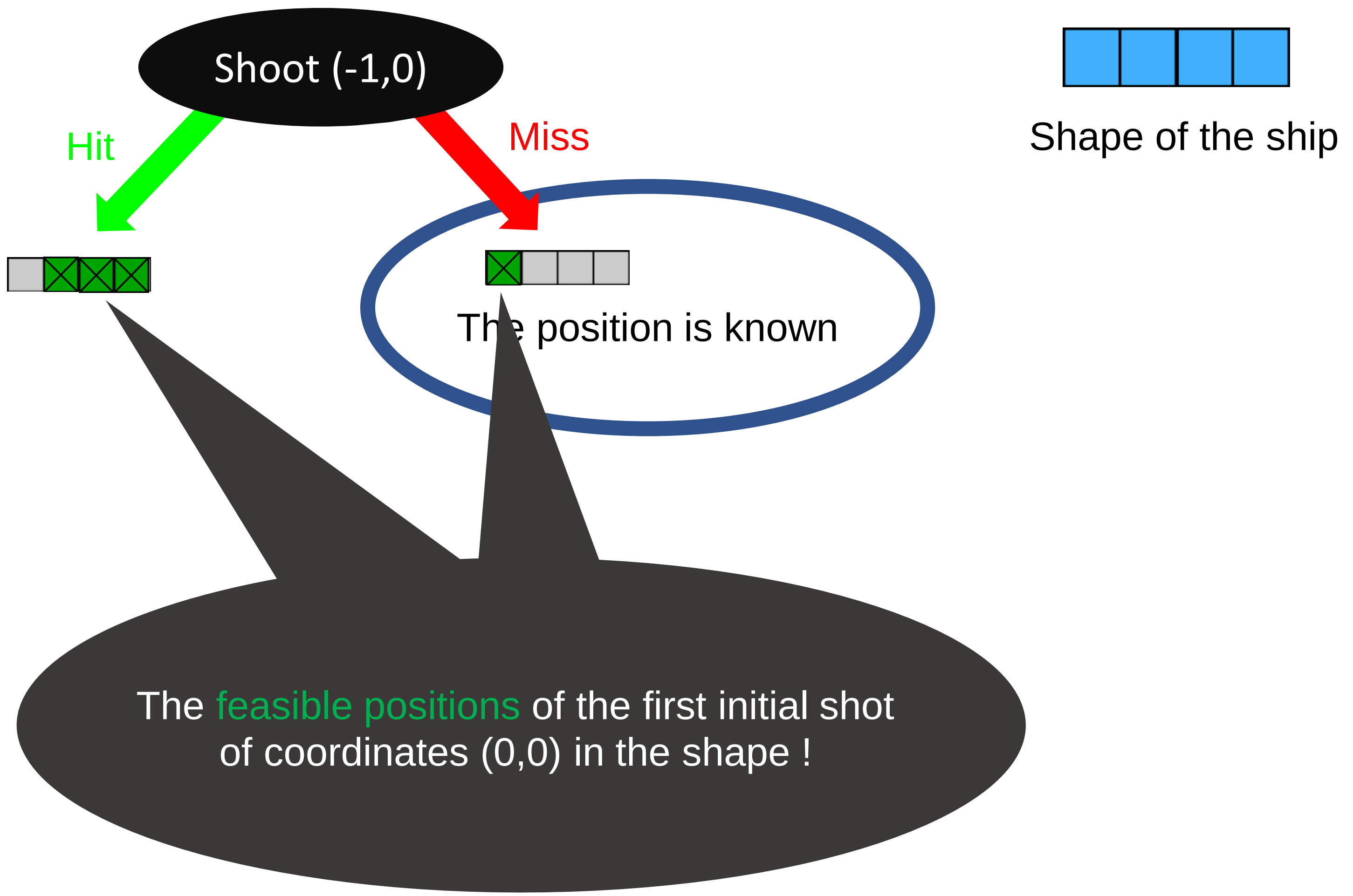
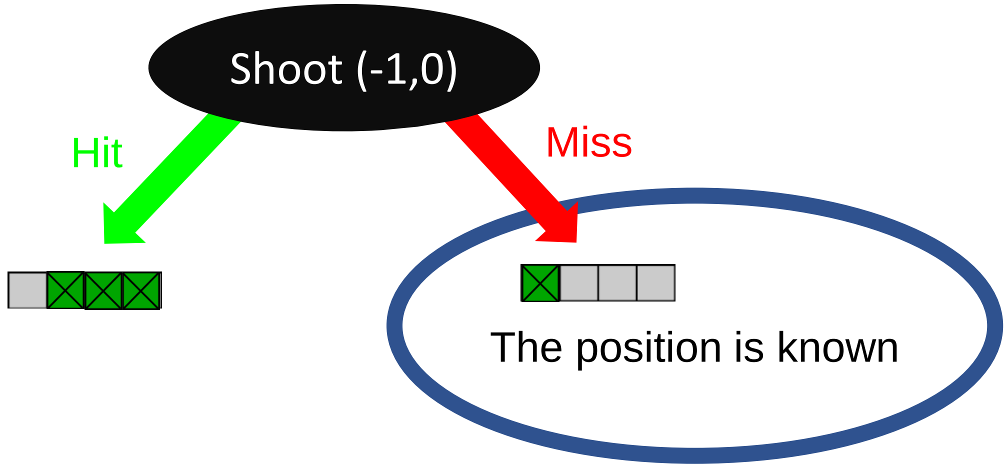


Shape of the ship


Shoot (-1,0)
Hit
Miss
The position is known
Shape of the ship


Shoot (-1,0)
Hit
Miss
Shape of the ship
The position is known
The feasible positions of the first initial shot
of coordinates (0,0) in the shape !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Hit
Miss
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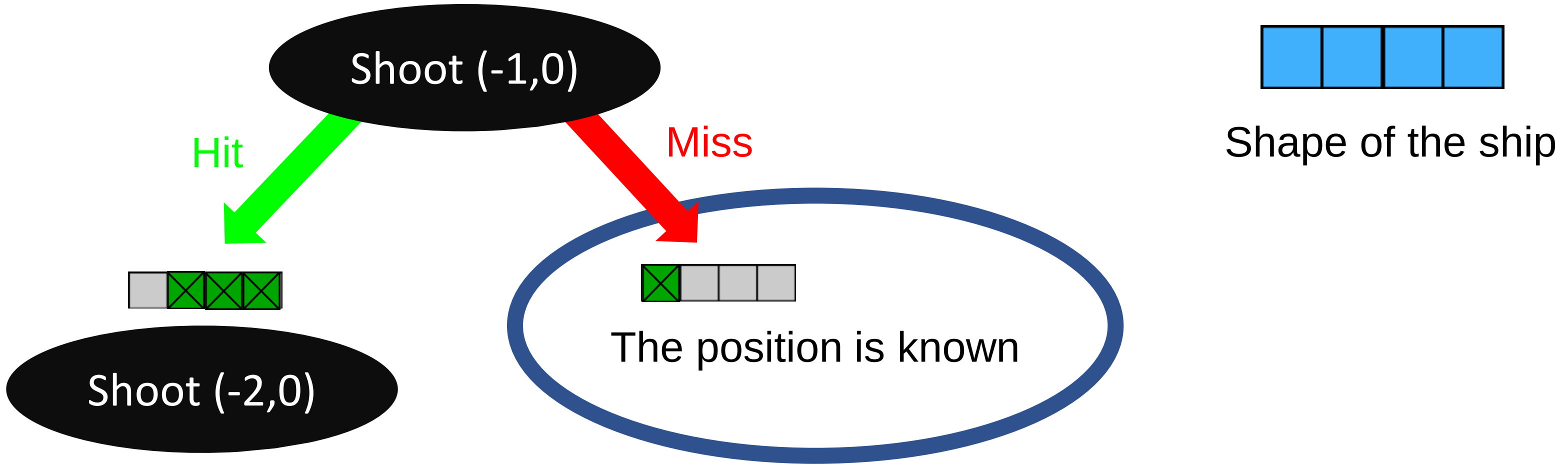
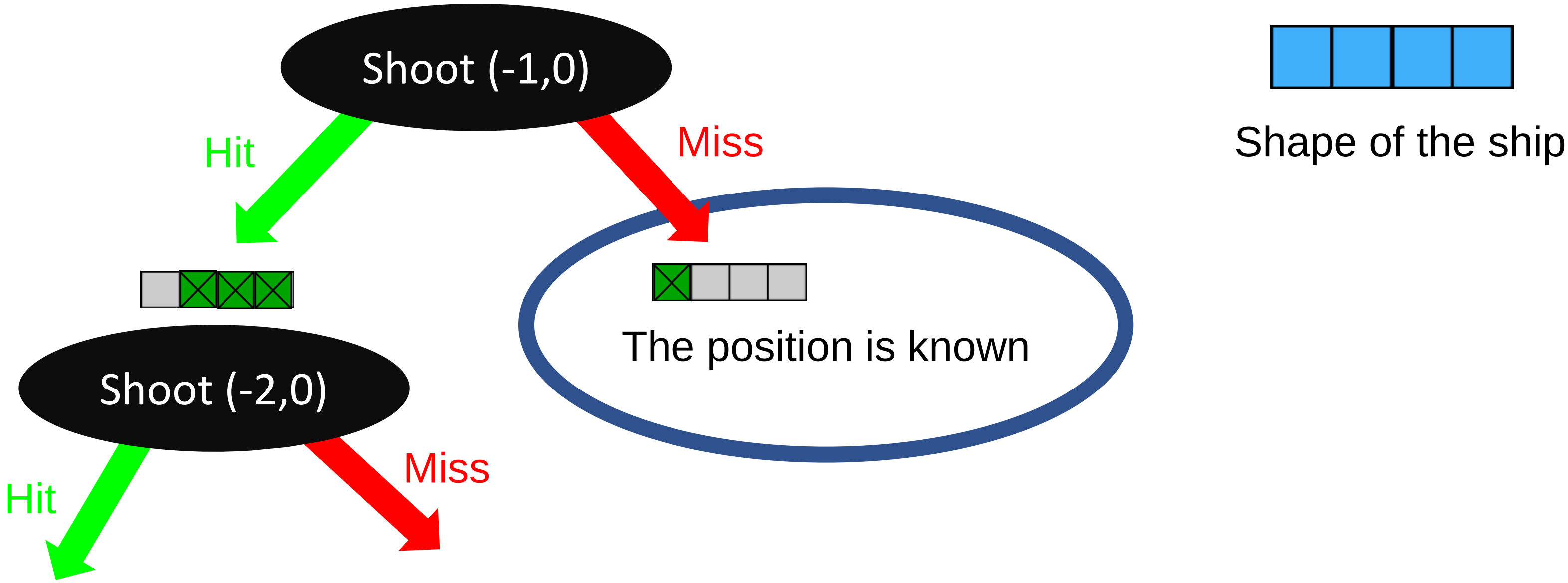
Shape of the ship


Shoot (-1,0)
Hit
Miss
Shoot (-2,0)
The position is known
Shape of the ship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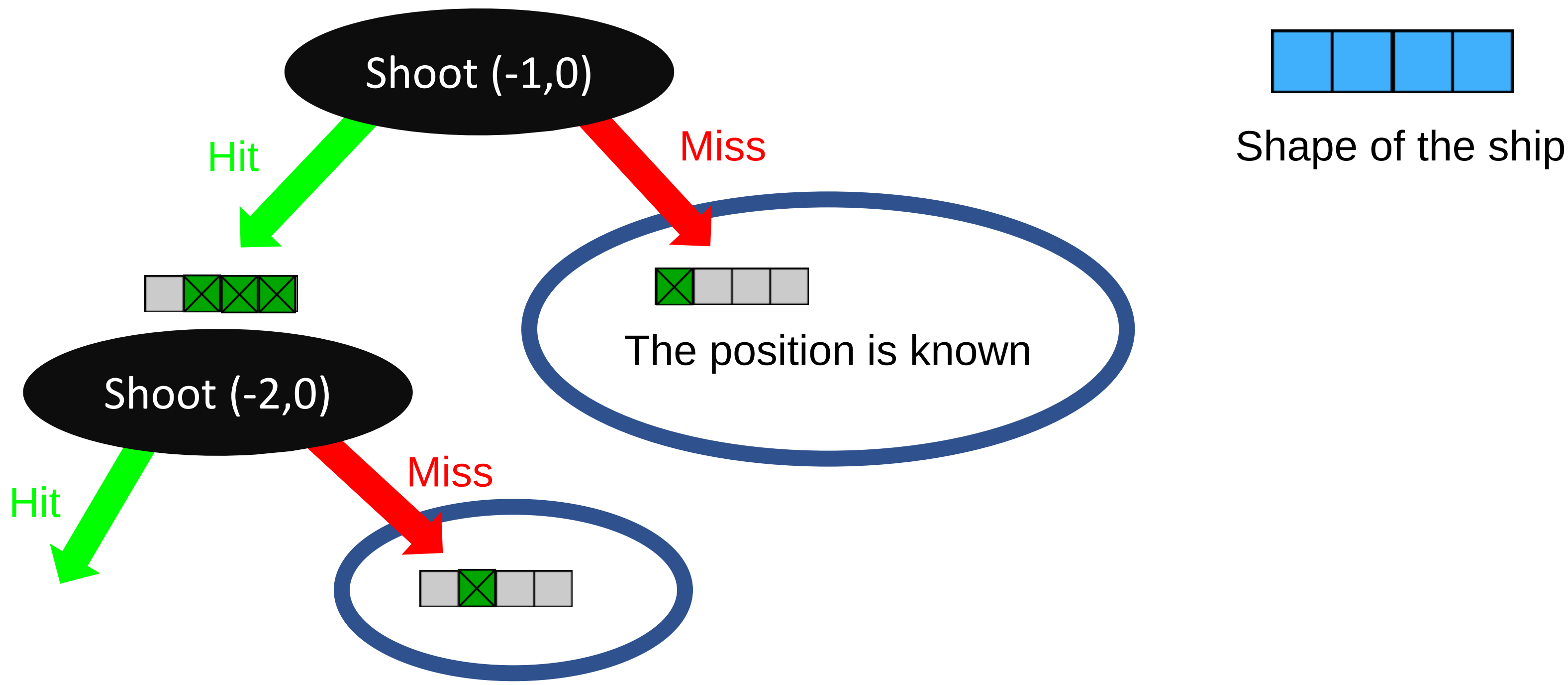
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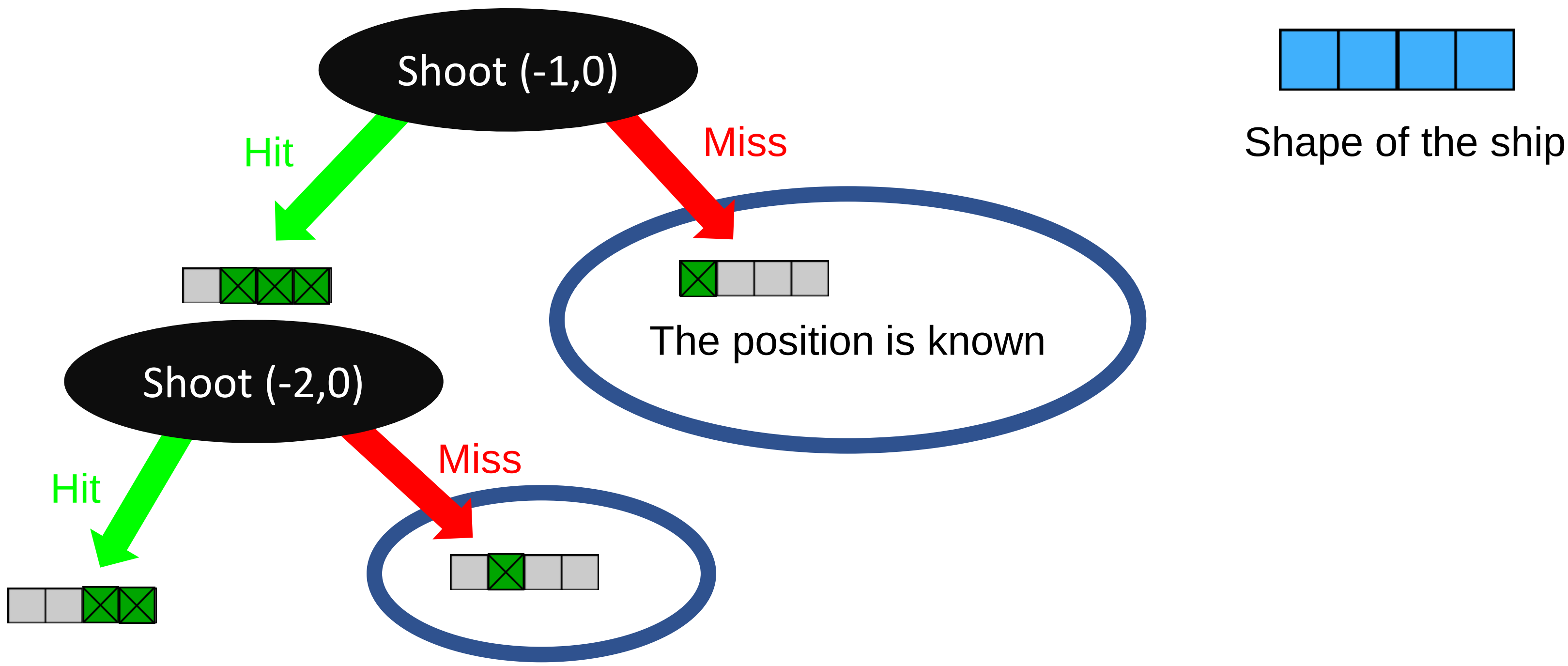
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Hit
Miss
Shape of the ship
The position is known
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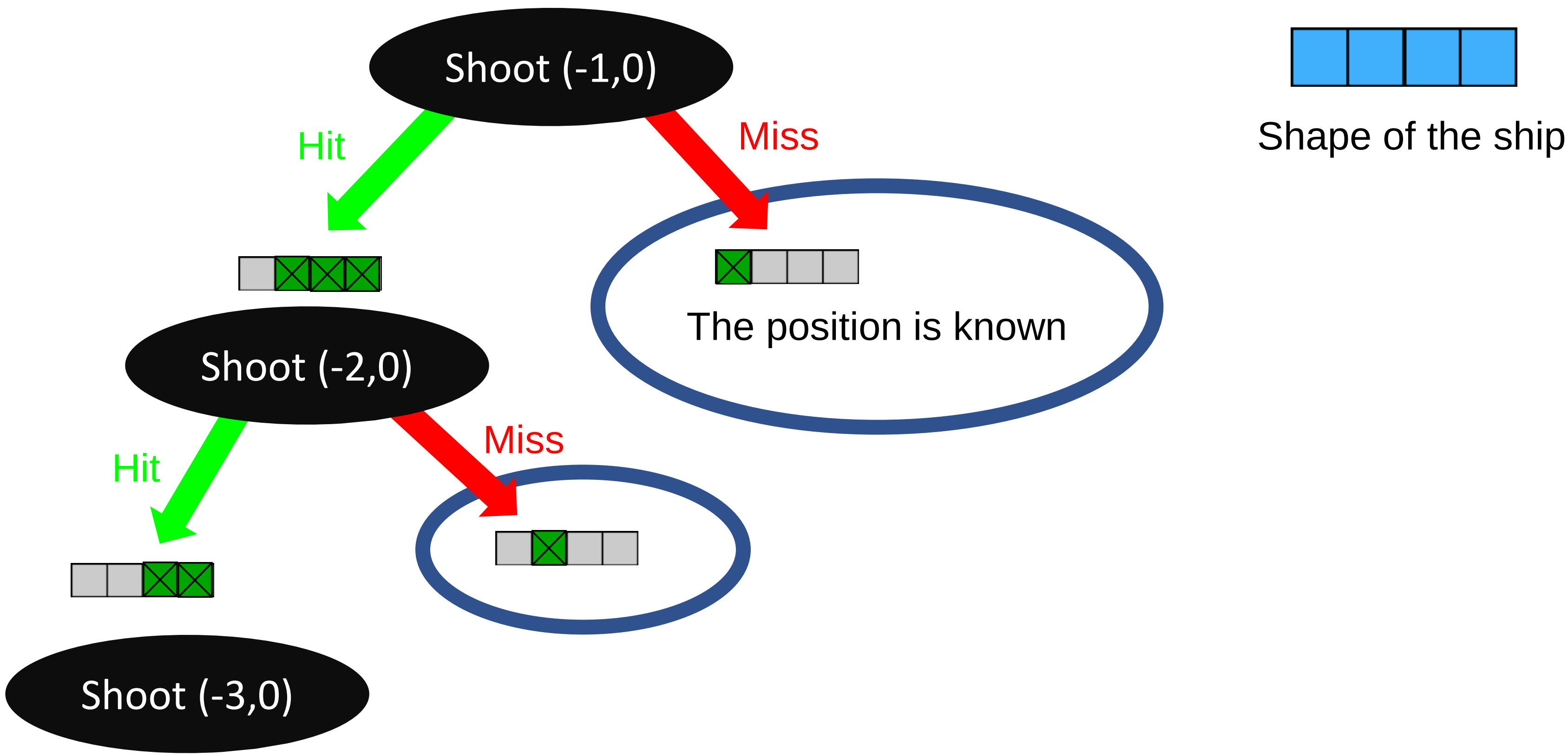
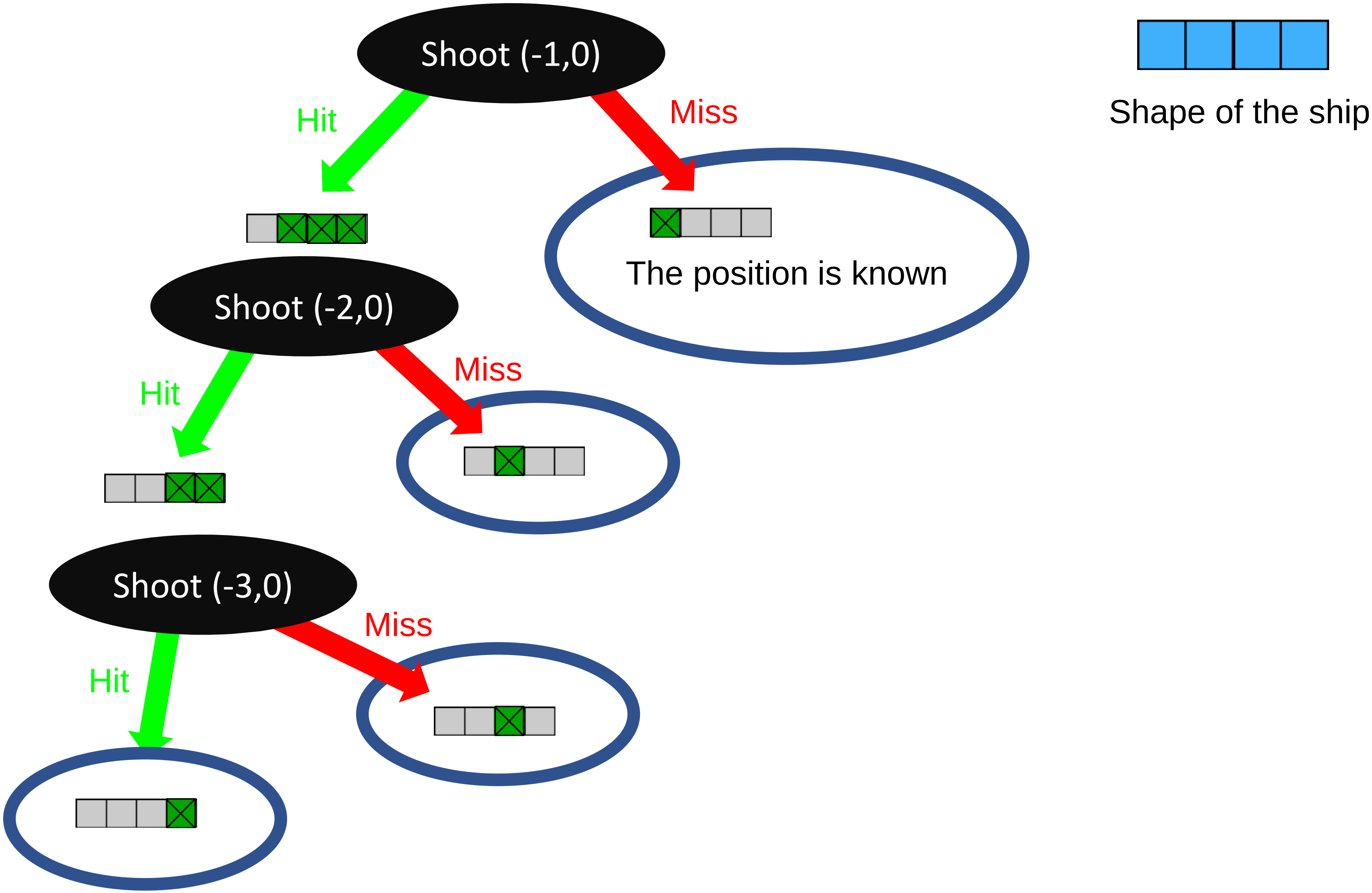
Miss


Shoot (-1,0)
Hit
Miss
Shoot (-2,0)
The position is known
Hit
Miss
Shoot (-3,0)
Shape of the ship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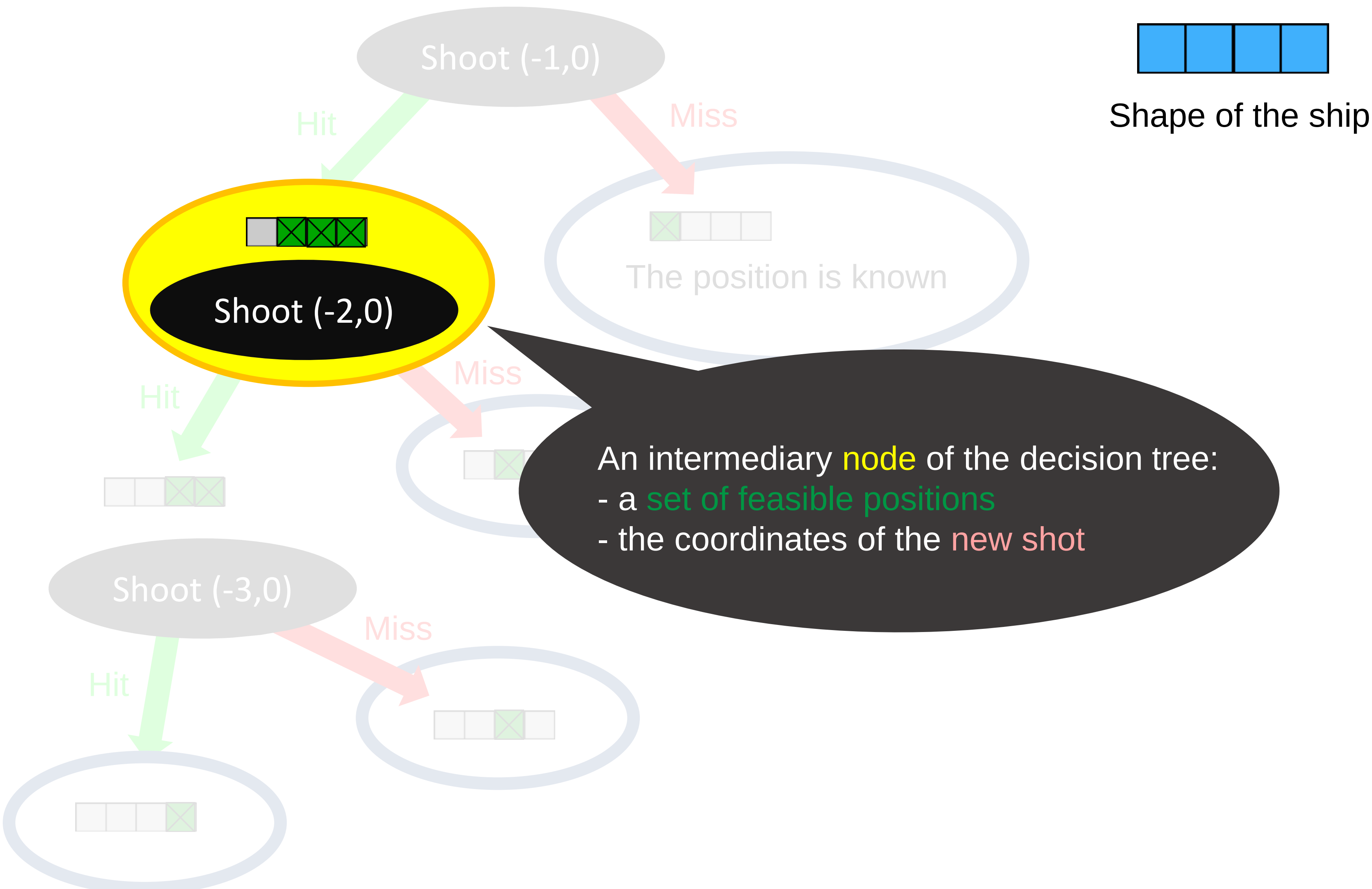
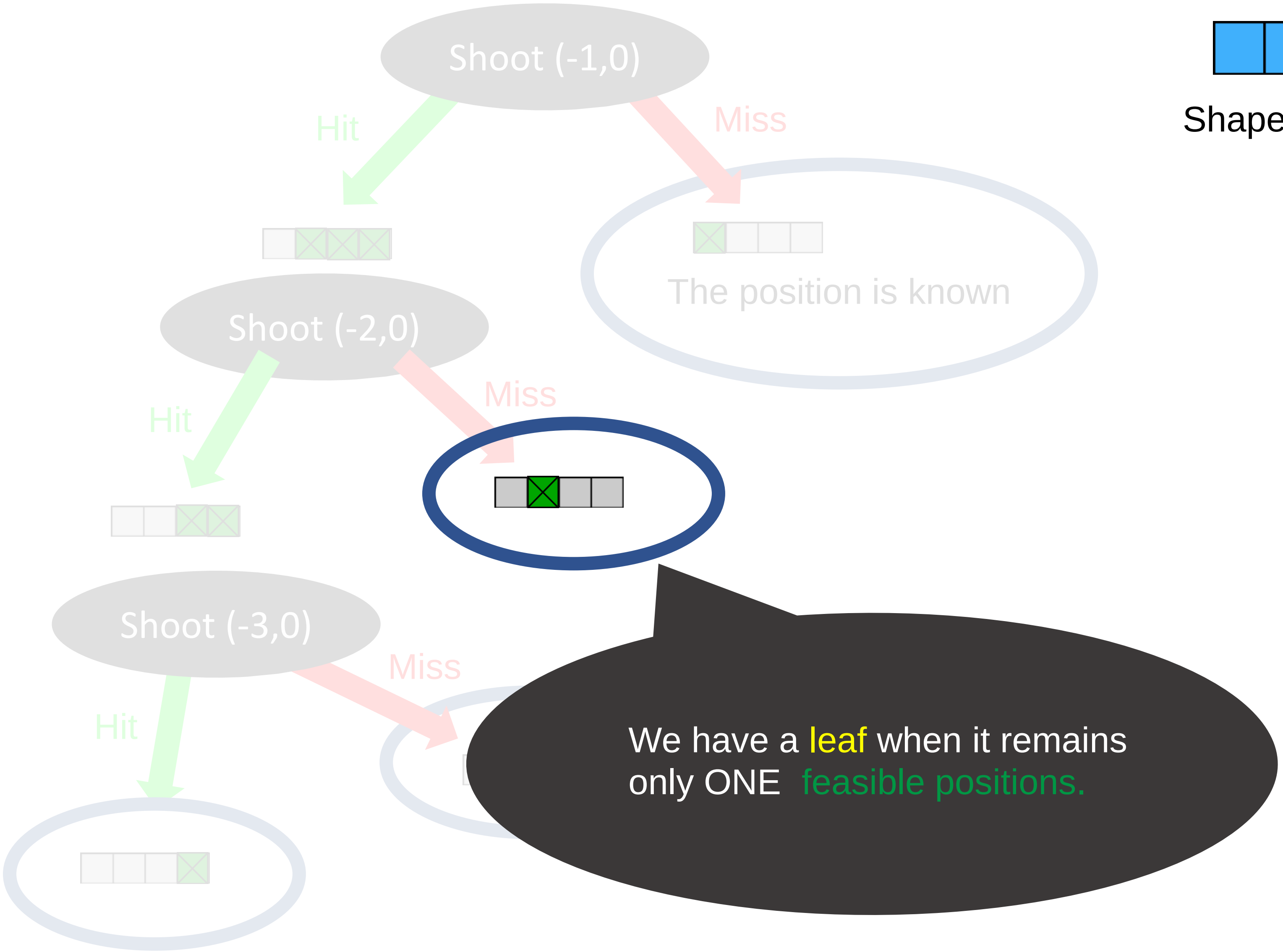
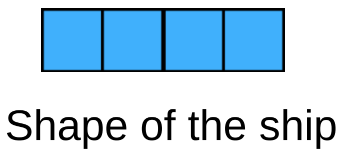

Shoot (-1,0)
Hit
Miss
The position is known
Shoot (-2,0)
Hit
Miss
Shoot (-3,0)
Hit
Miss
Shape of the ship
An intermediary node of the decision tree:
- a set of feasible positions
- the coordinates of the new shot

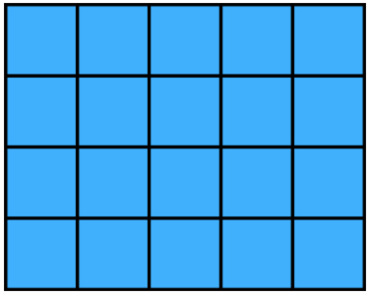

Shoot (-1,0)
Hit
Miss
The position is known
Shoot (-2,0)
Hit
Miss
Shoot (-3,0)
Hit
Miss
We have a leaf when it remains only ONE feasible positions.


Shape of the ship

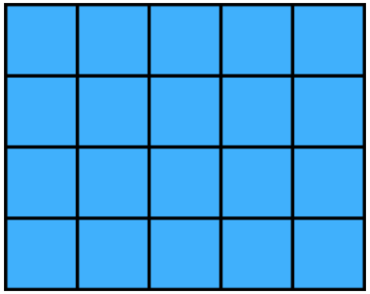
2 different ways to
model an algorithm

With shooting rules
(for simple algorithms)

With a decision tree
(when there are many cases)

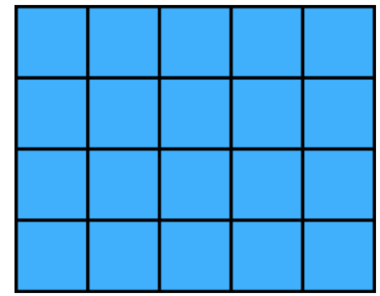


Shape of the ship

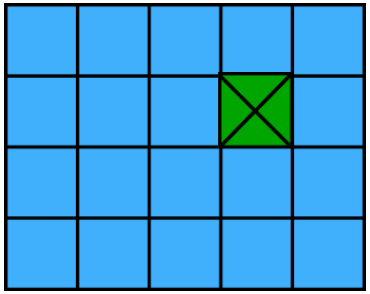


Shape of the ship

What is the best strategy ?



1) Shoot on the left of the previous shot until having a miss.



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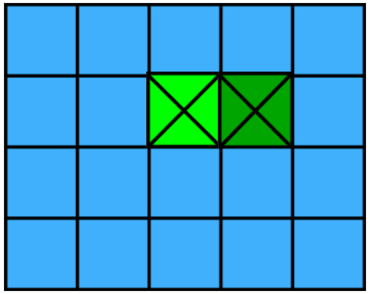

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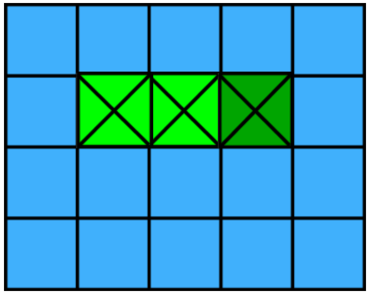

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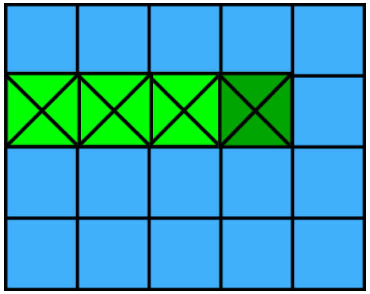

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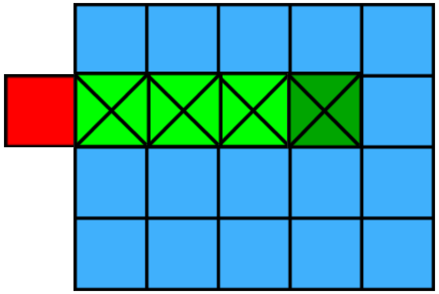
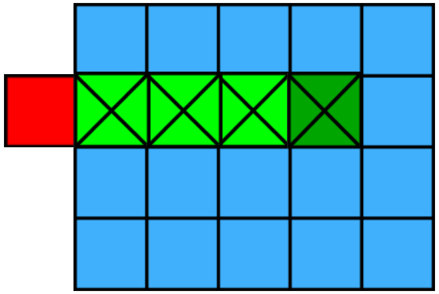
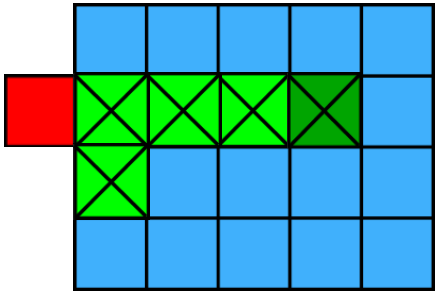




1) Shoot on the left of the previous shot until having a miss.

2) Then shoot down until having a miss.
Then the position of the ship is known.



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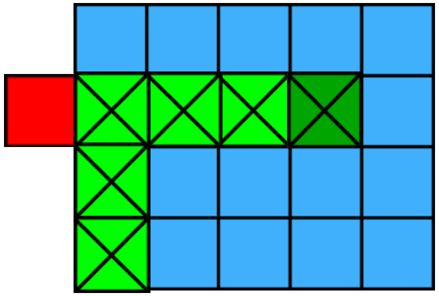

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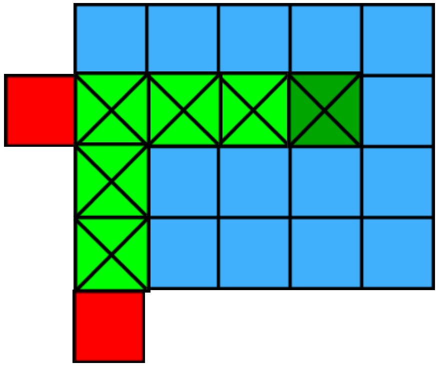

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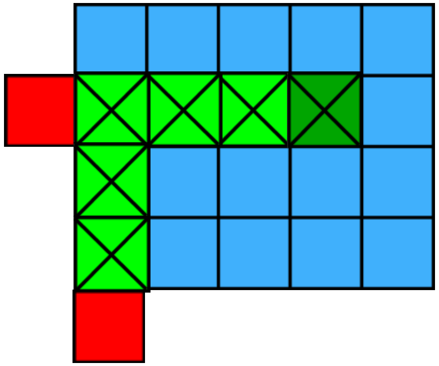
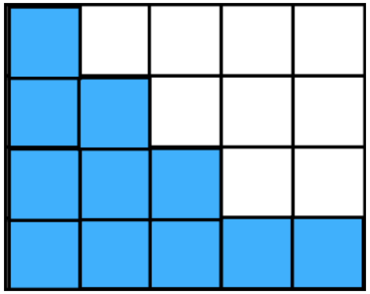
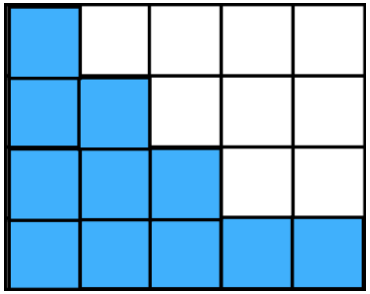


It allows to determine the position of the ship with at most two misses



A new shape

The previous algorithm works: it determines the position with at most 2 misses.



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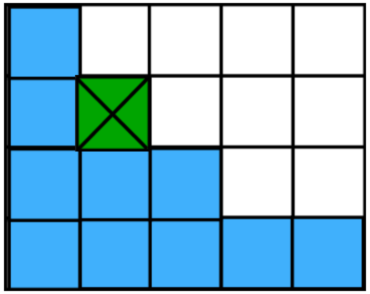

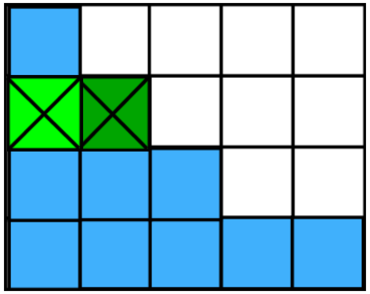

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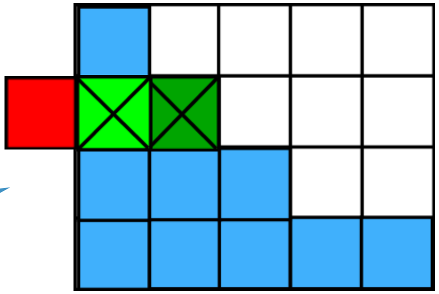

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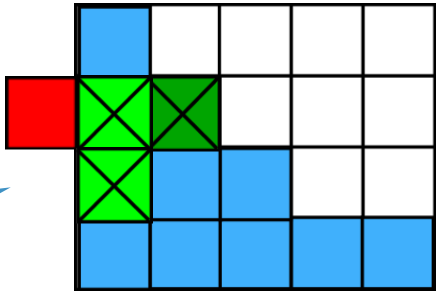

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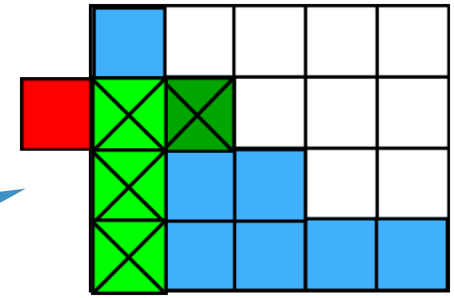

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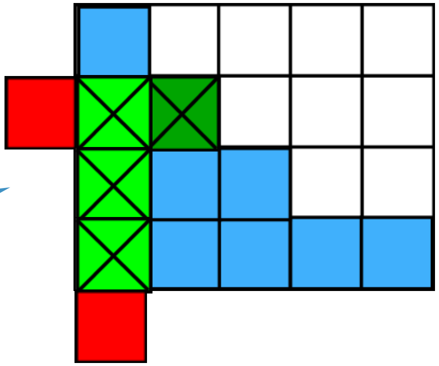

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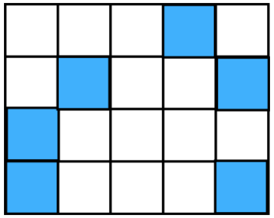
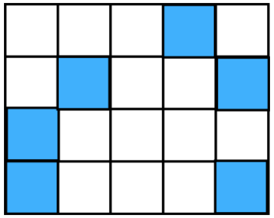
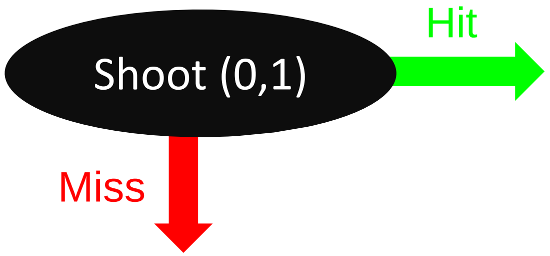


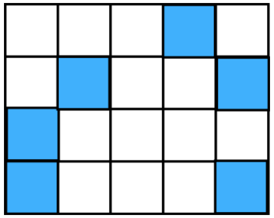
Shape

Shoot (0,1)

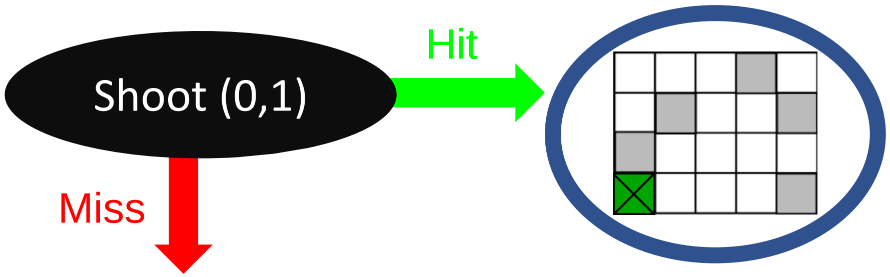


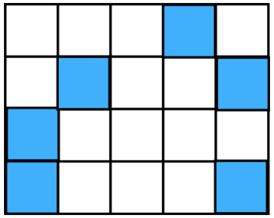
Shape





Shape

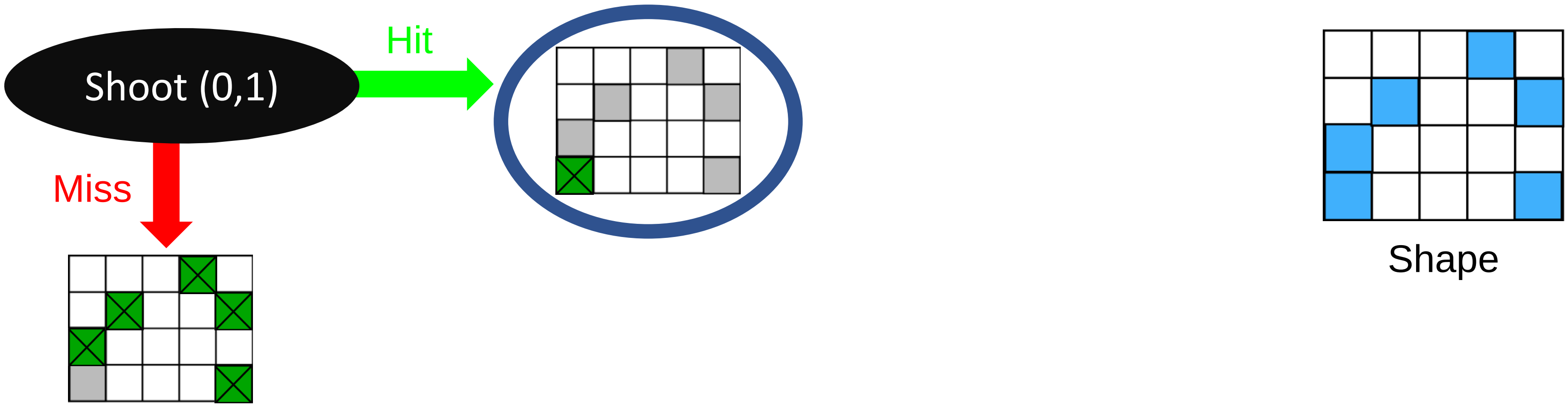


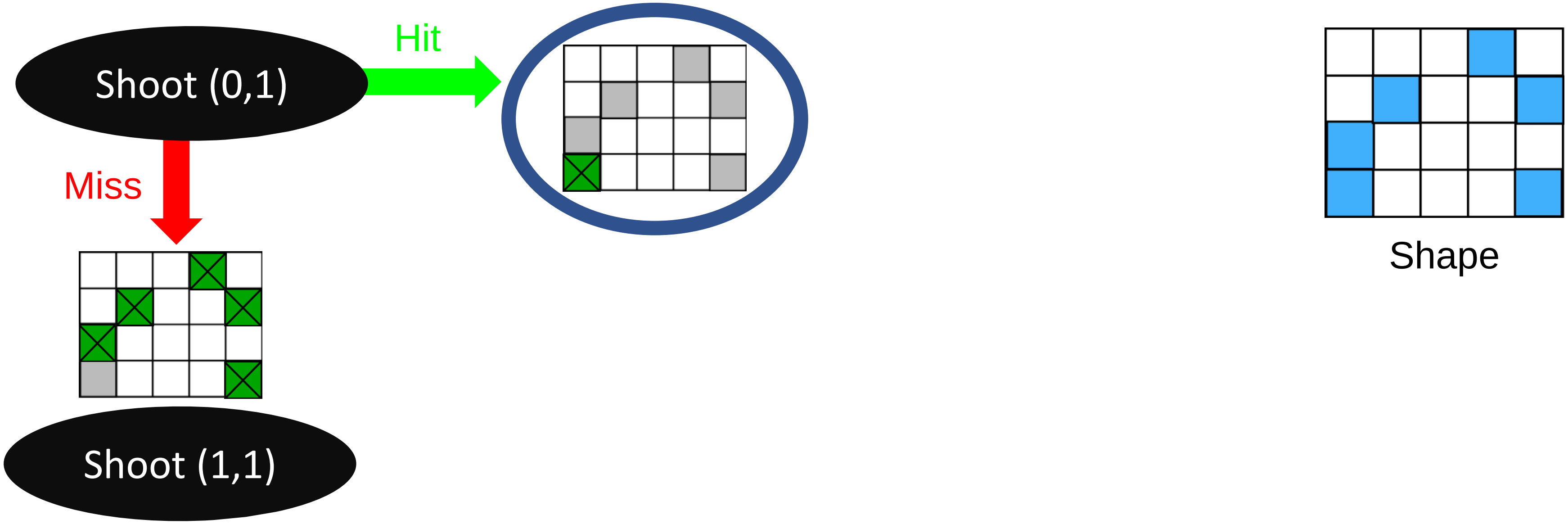


Shape

Shooting Algorithms

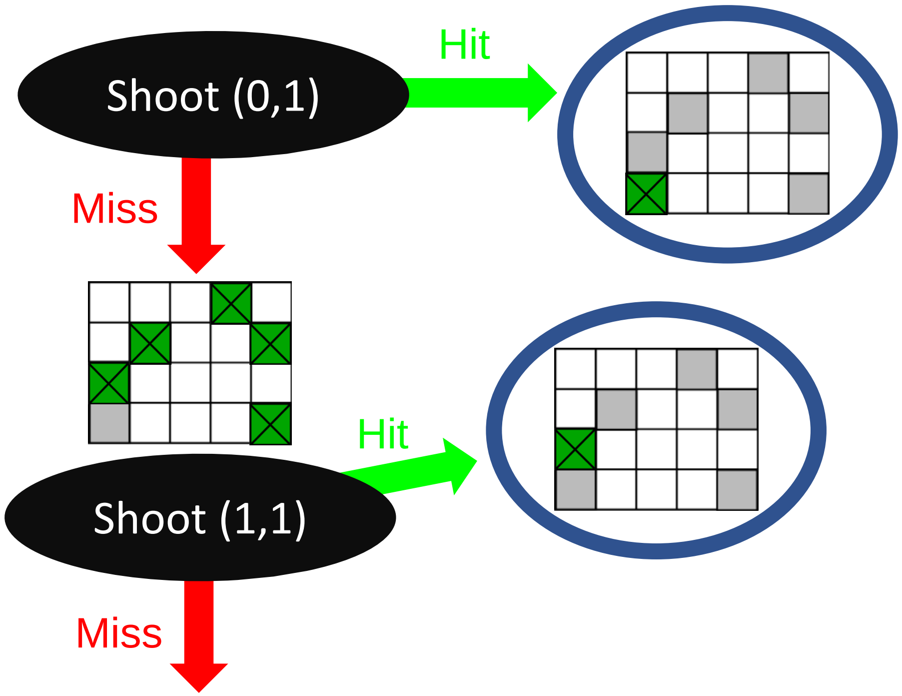
Example 4

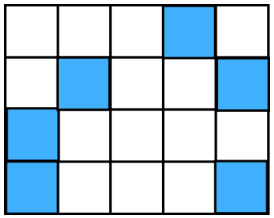



Shoot (0,1)
Hit
Miss
Shoot (1,1)
Shape

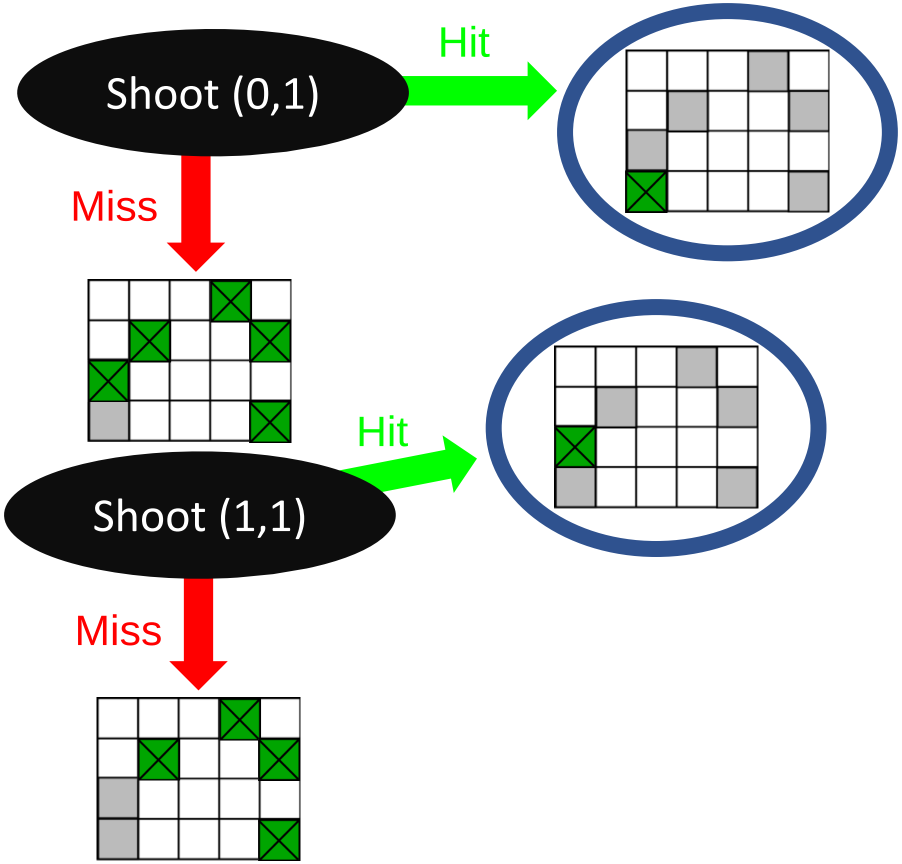
Shooting Algorithms

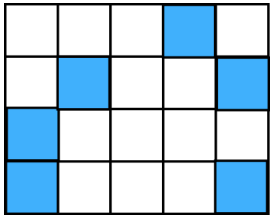
Example 4



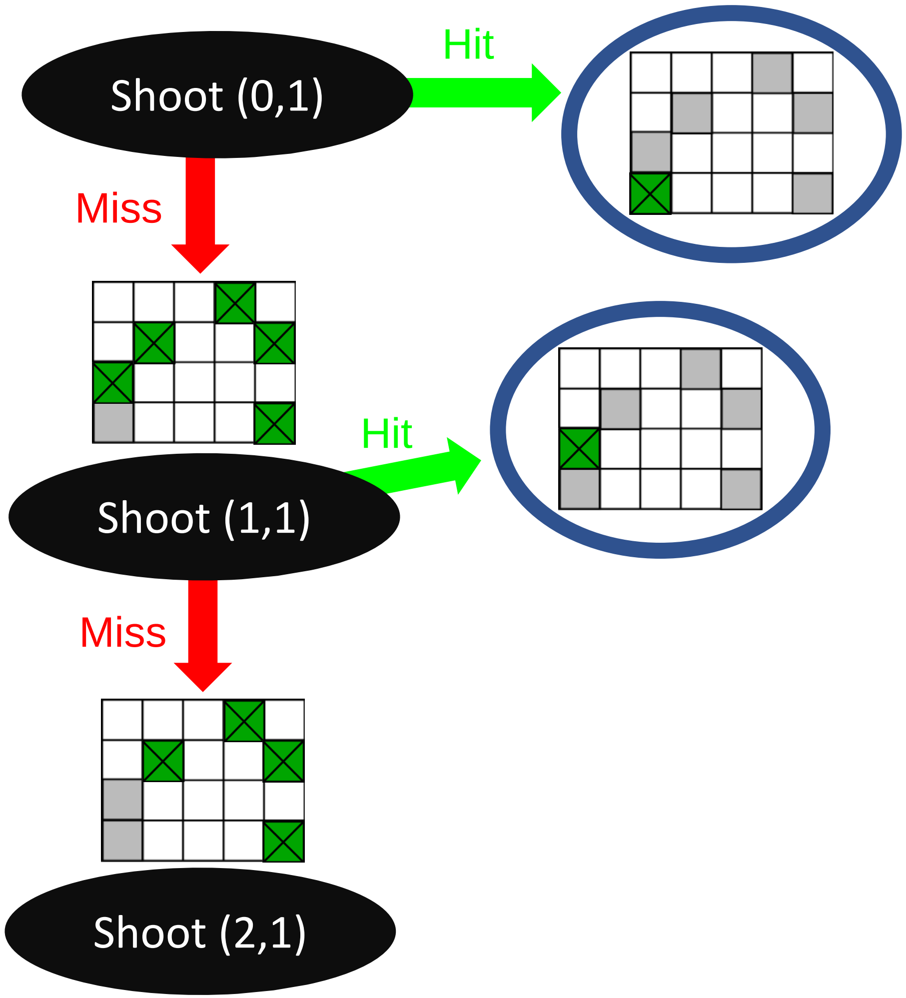


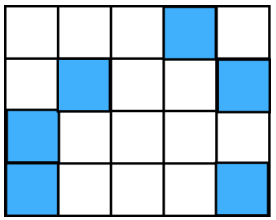
Shape



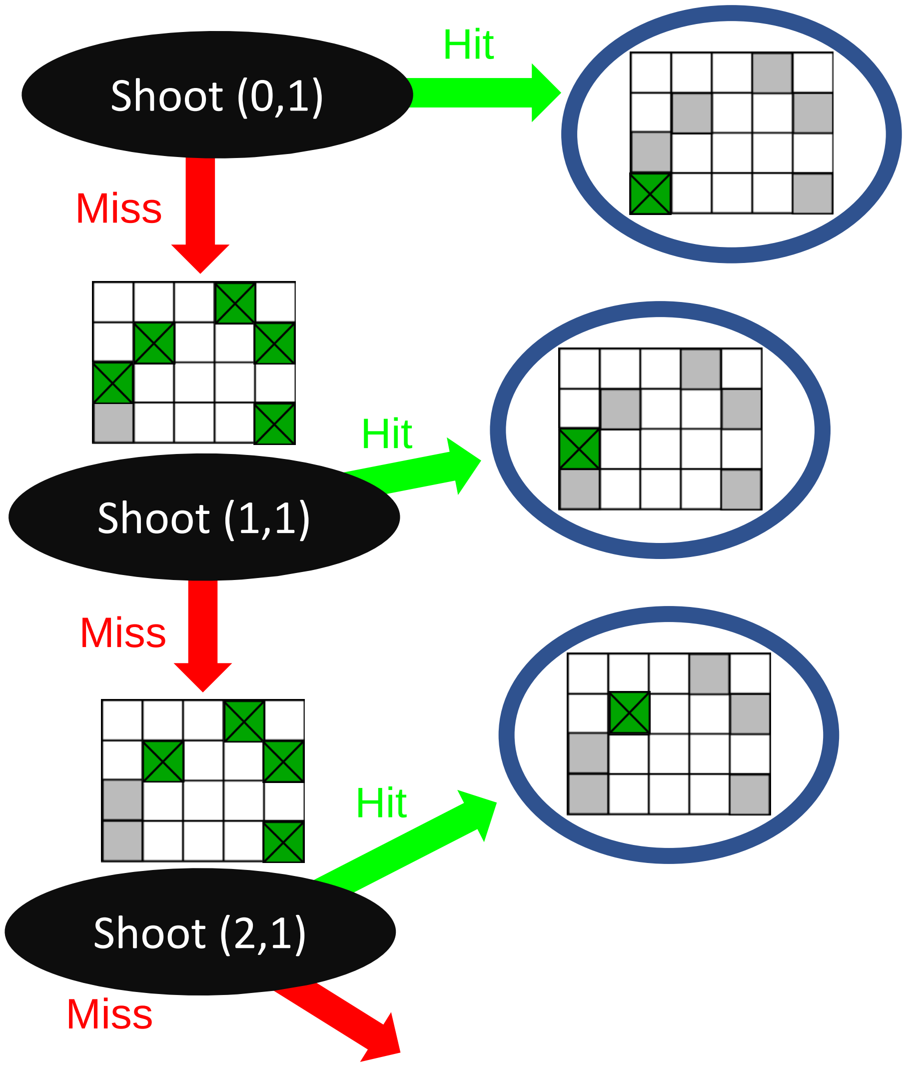


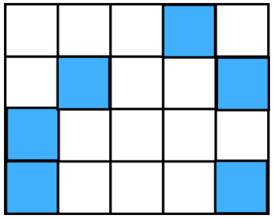
Shape




Shape

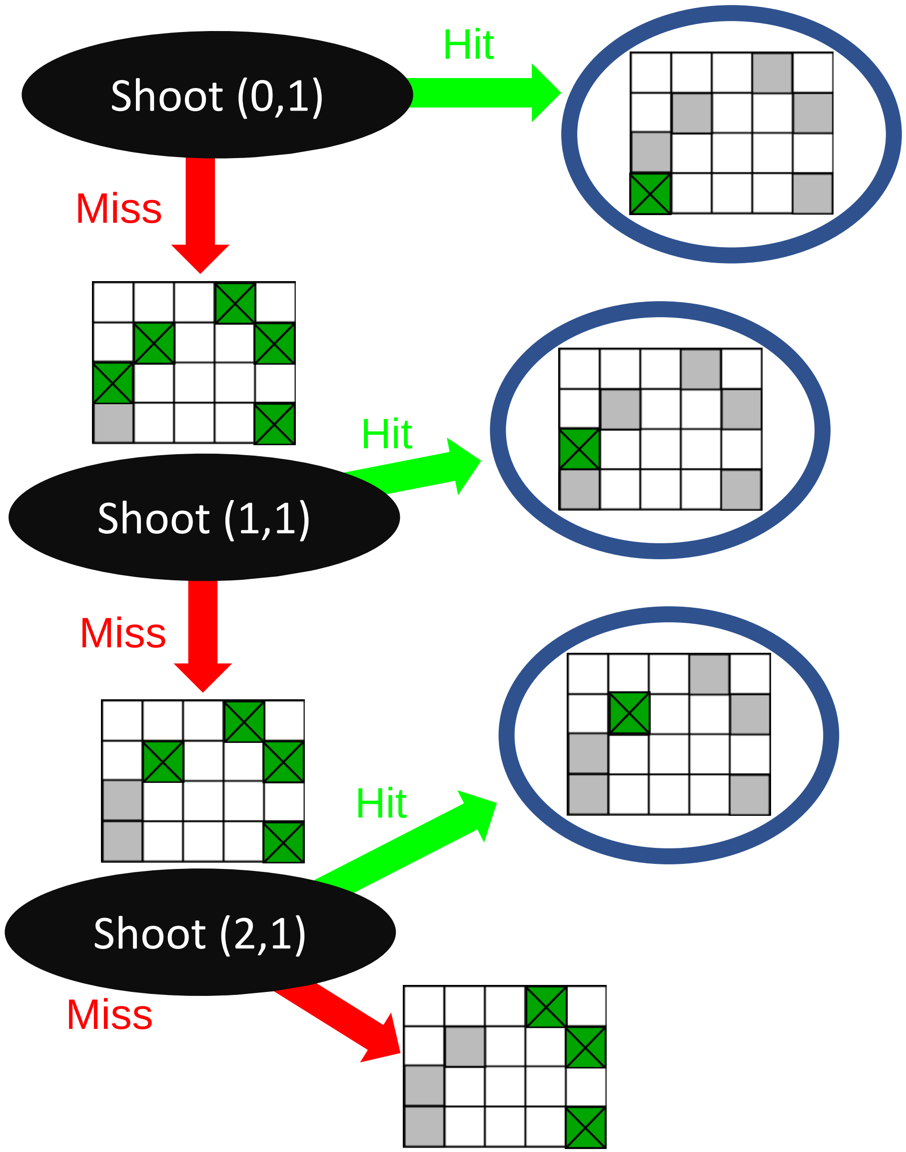
Example 4

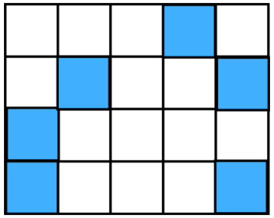




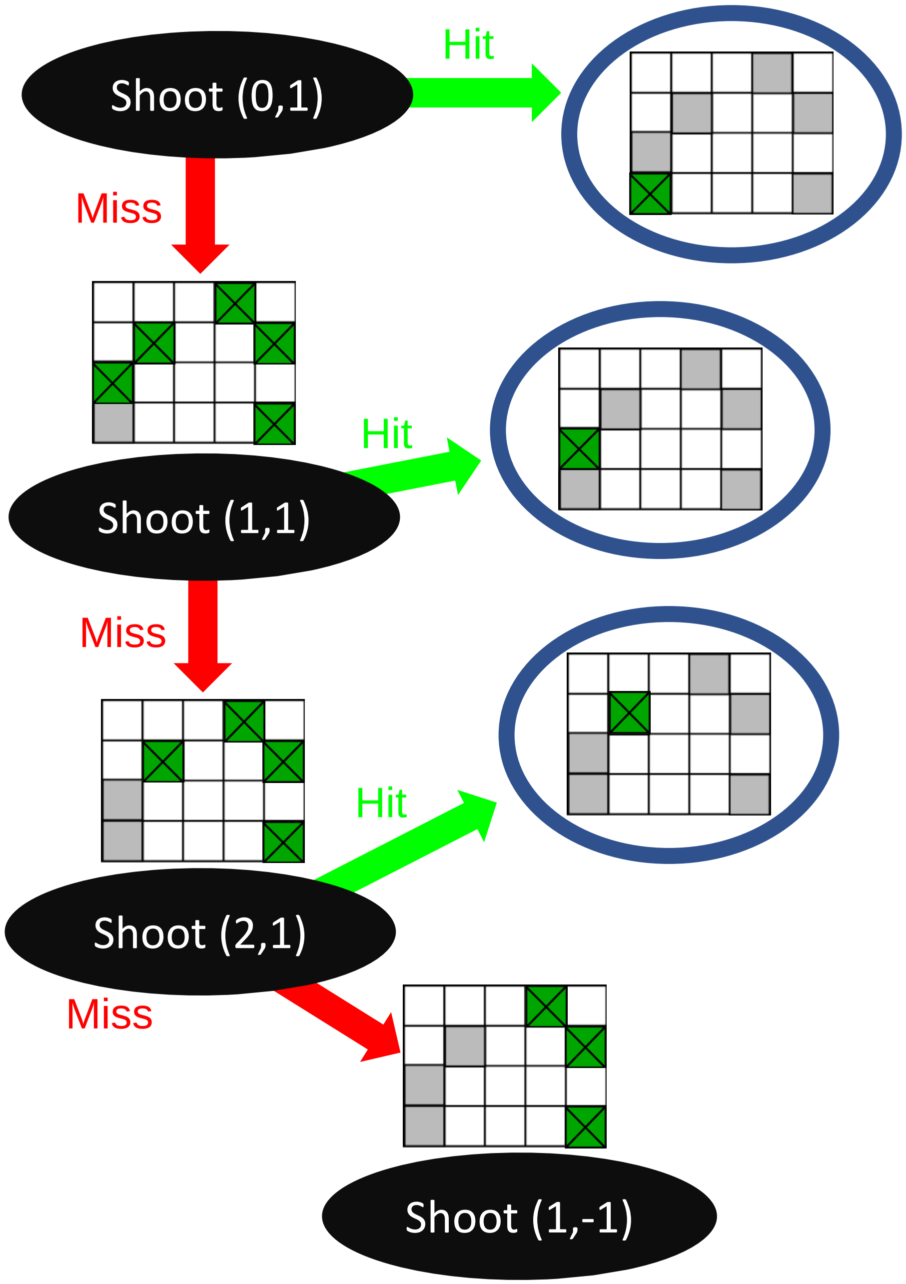
Shape

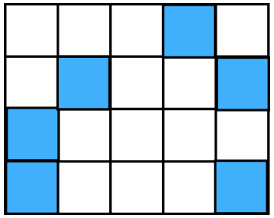
Another example

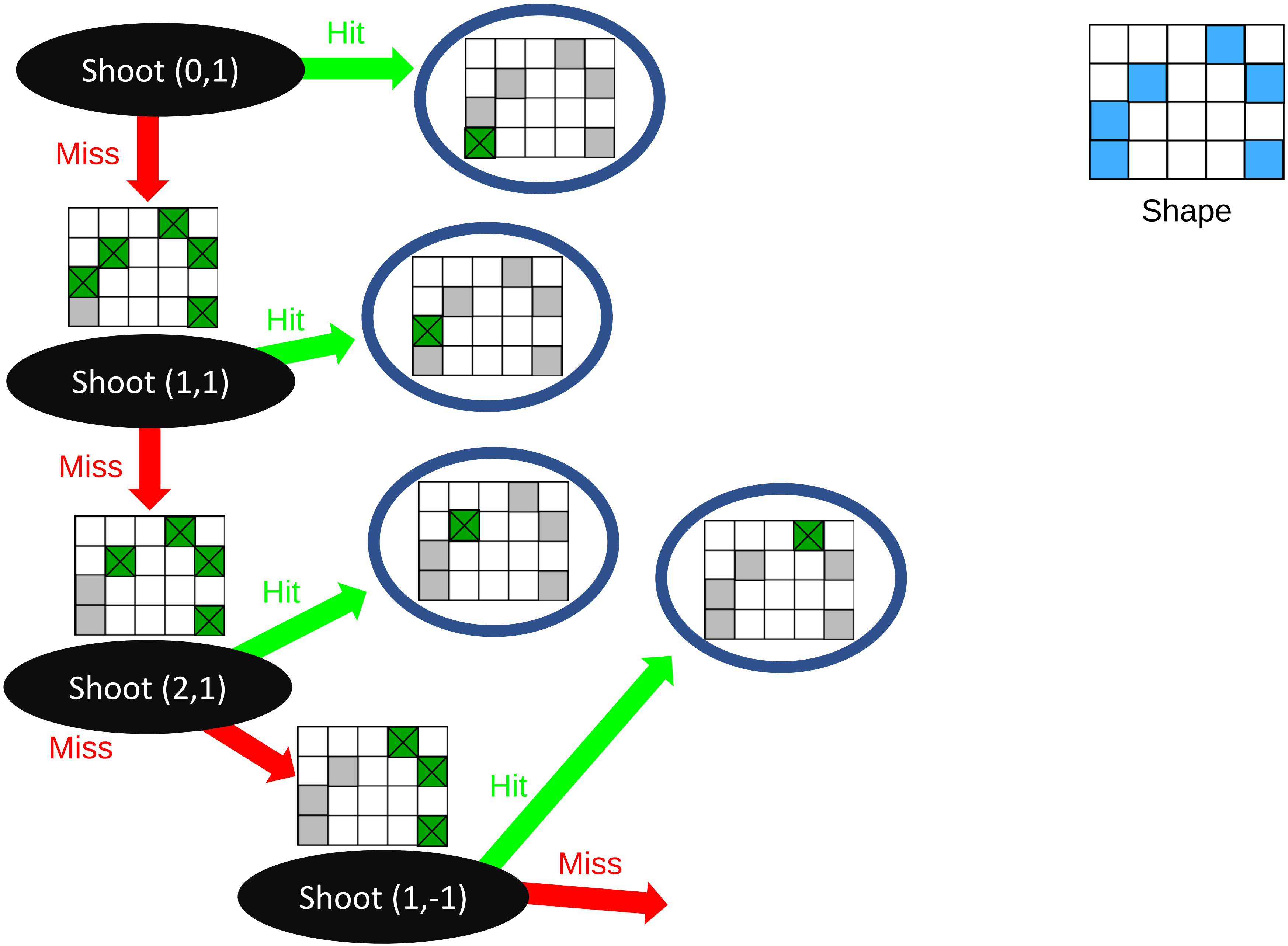




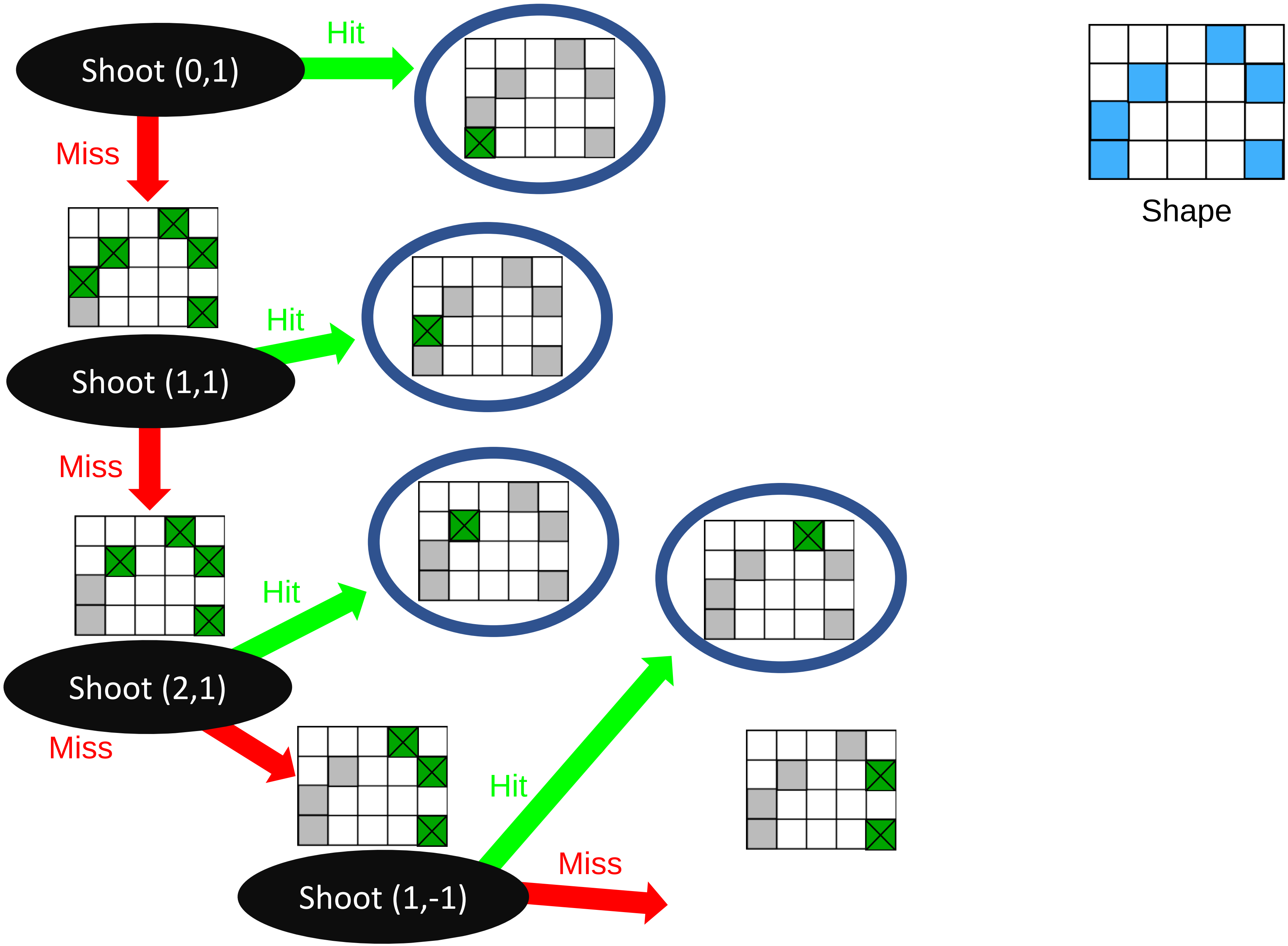
Shape

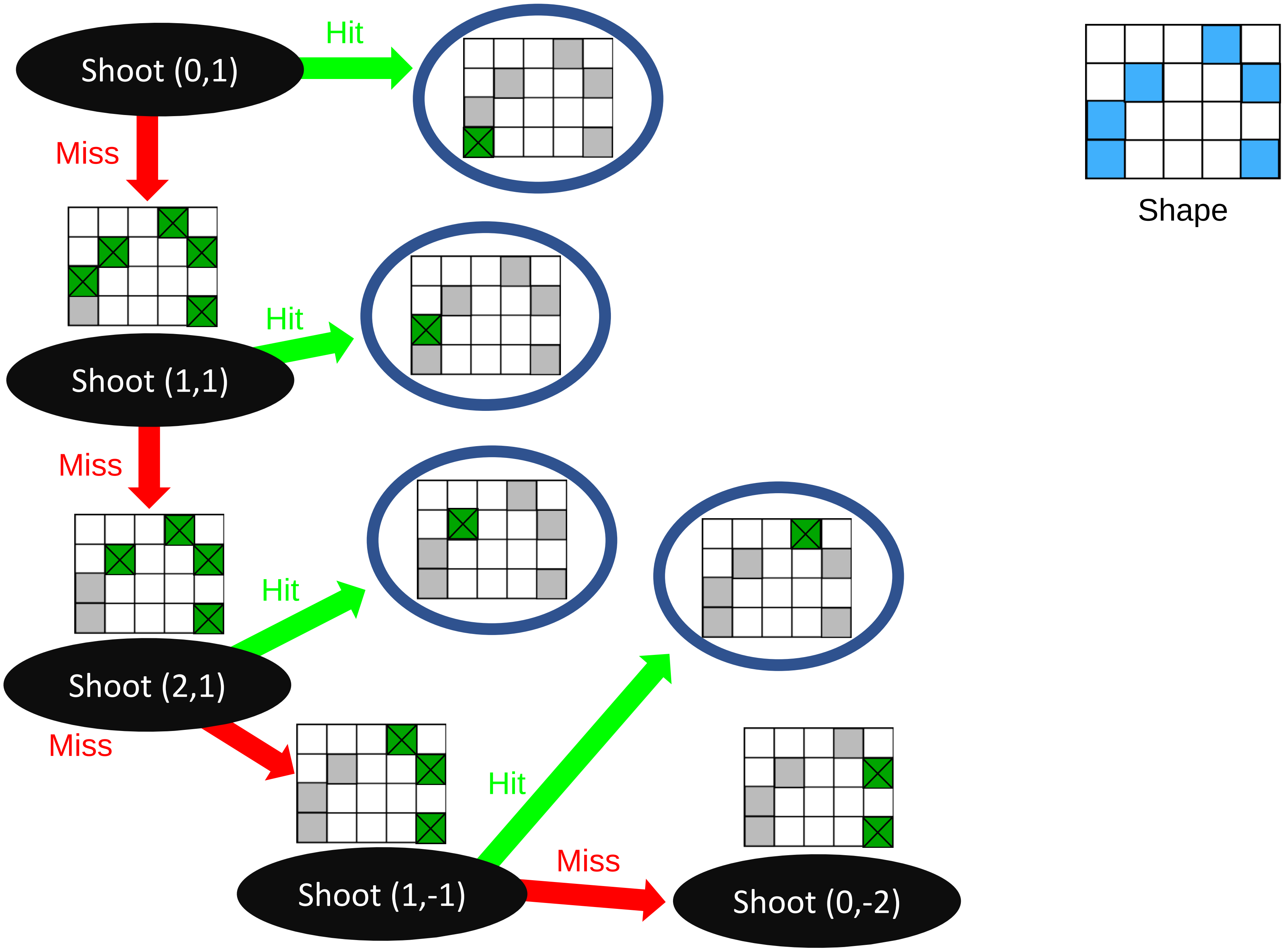



Shape

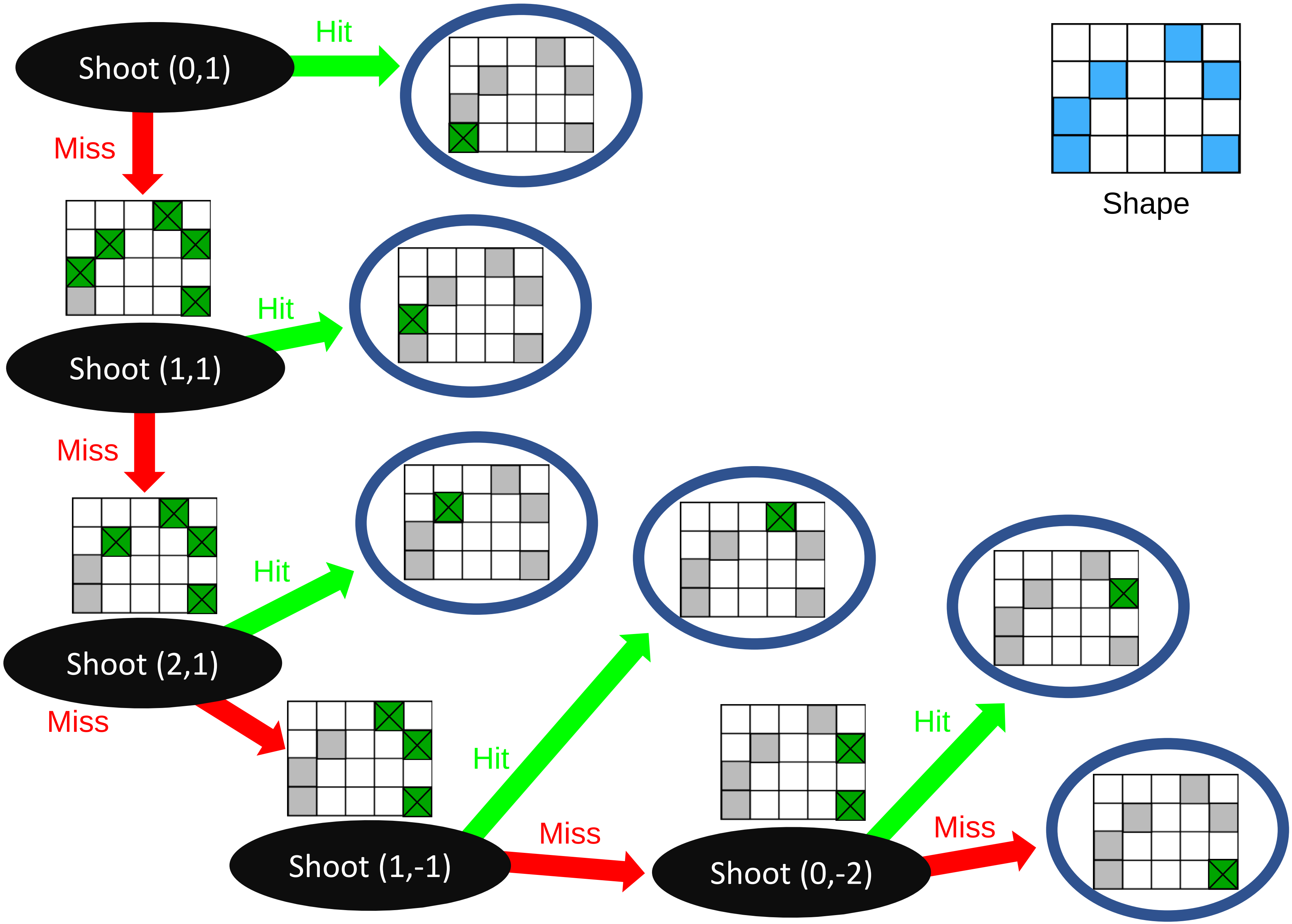

Shoot (0,1)
Hit
Miss
Shoot (1,1)
Hit
Miss
Shoot (2,1)
Hit
Miss
Shoot (1,-1)
Hit
Miss
Shape

Example 4


Shoot (0,1)
Hit
Miss
Shoot (1,1)
Hit
Miss
Shoot (2,1)
Hit
Miss
Shoot (1,-1)
Hit
Miss
Shape

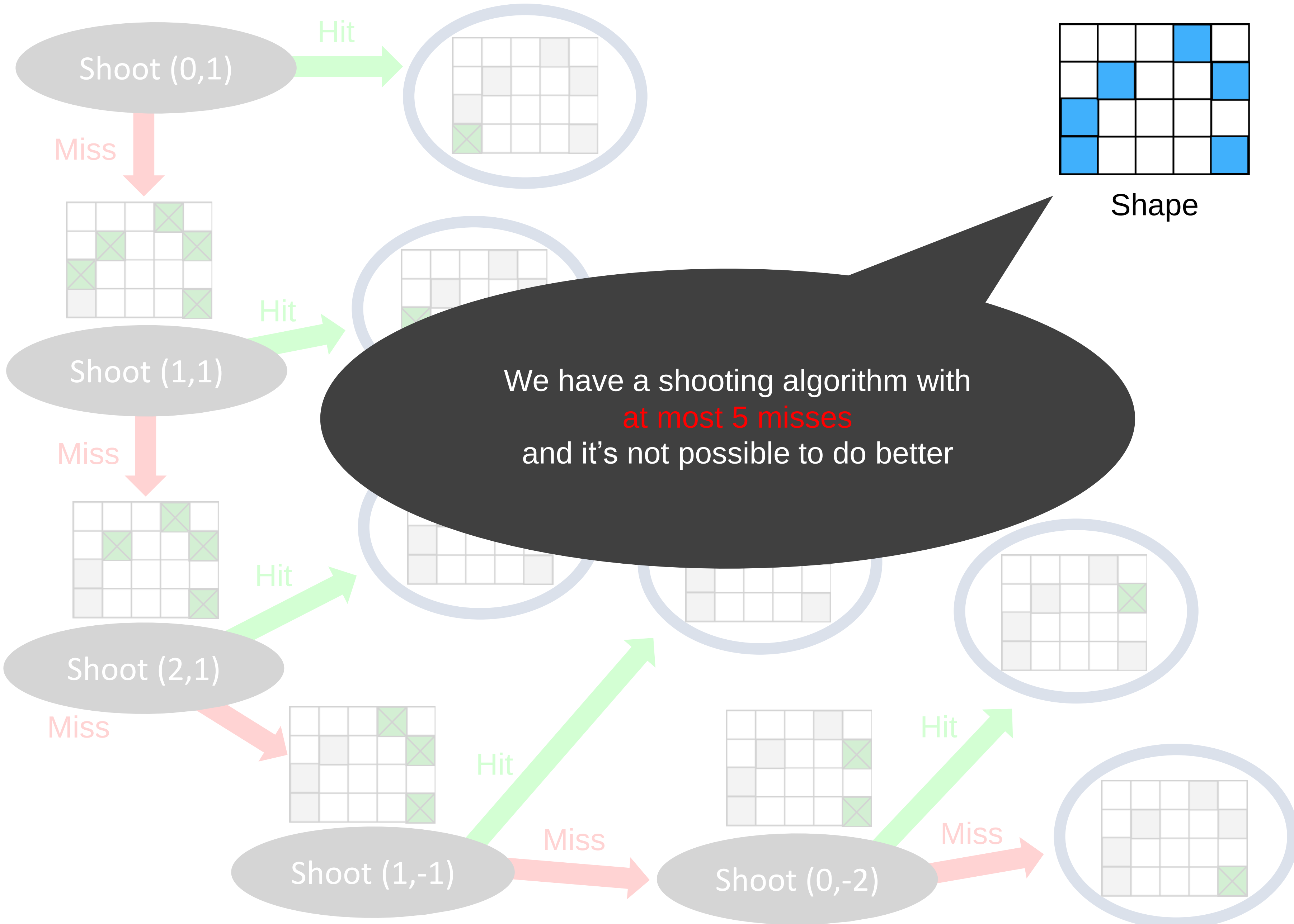

Shoot (0,1)
Hit
Miss
Shoot (1,1)
Hit
Miss
Shoot (2,1)
Hit
Miss
Shoot (1,-1)
Hit
Miss
Shoot (0,-2)
Shape

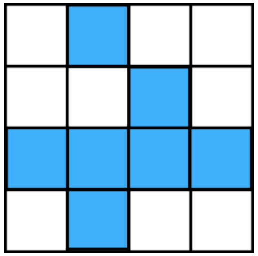
Example 4


Shoot (0,1)
Hit
Miss
Shoot (1,1)
Hit
Miss
Shoot (2,1)
Hit
Miss
Shoot (1,-1)
Hit
Miss
Shoot (0,-2)
Hit
Miss
Shape

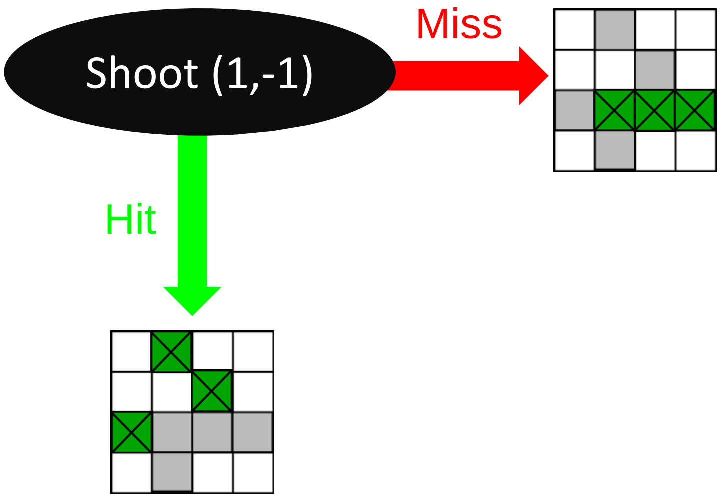
II Shooting Algorithms

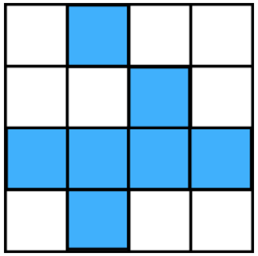
Example 4



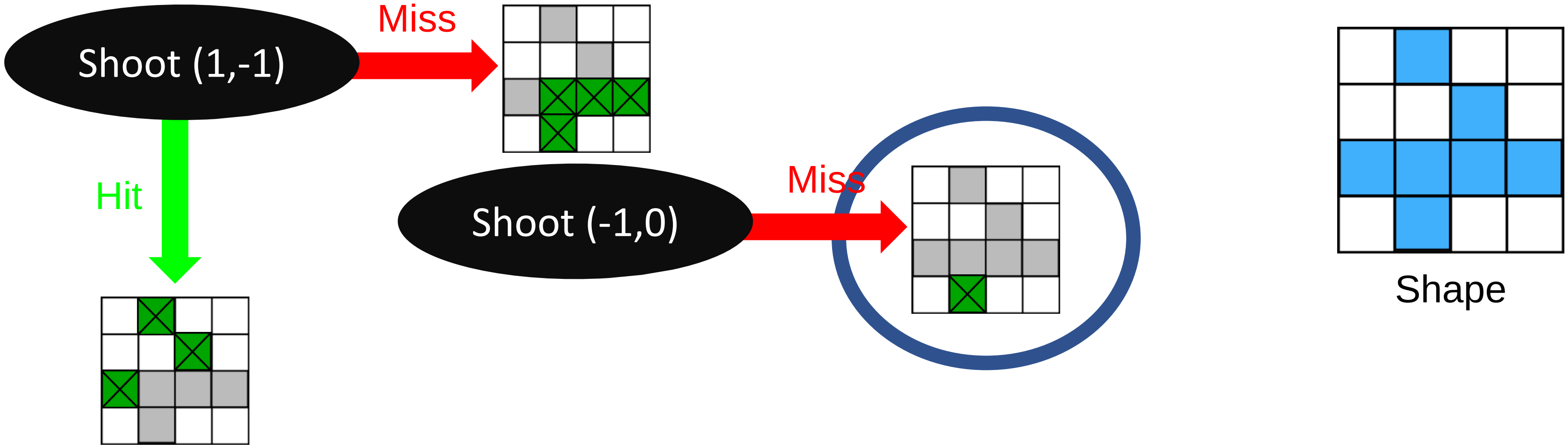


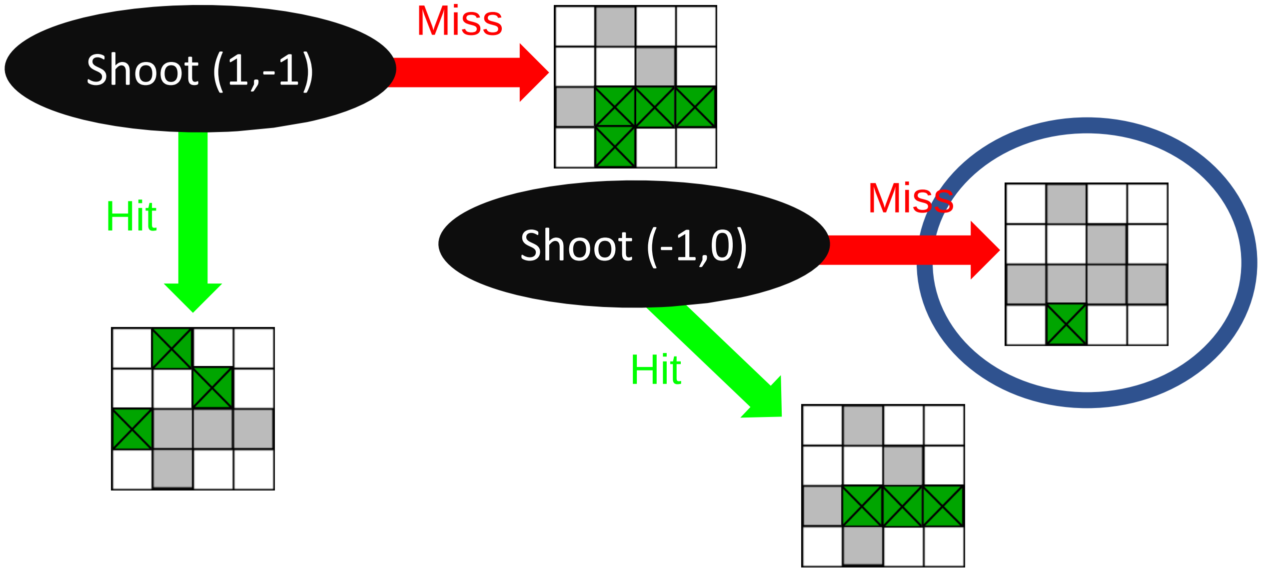
Shape

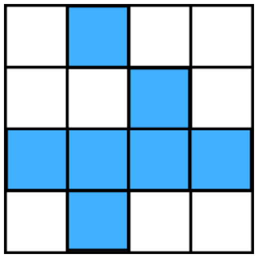


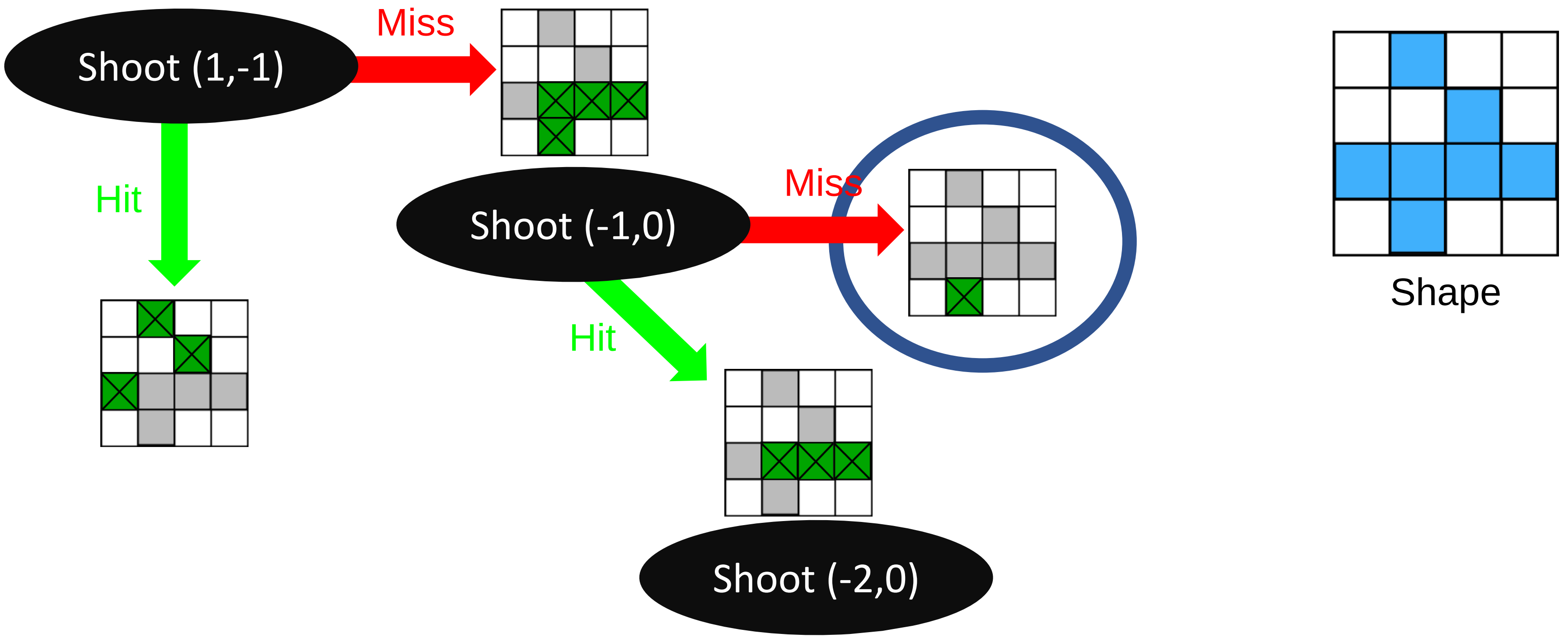


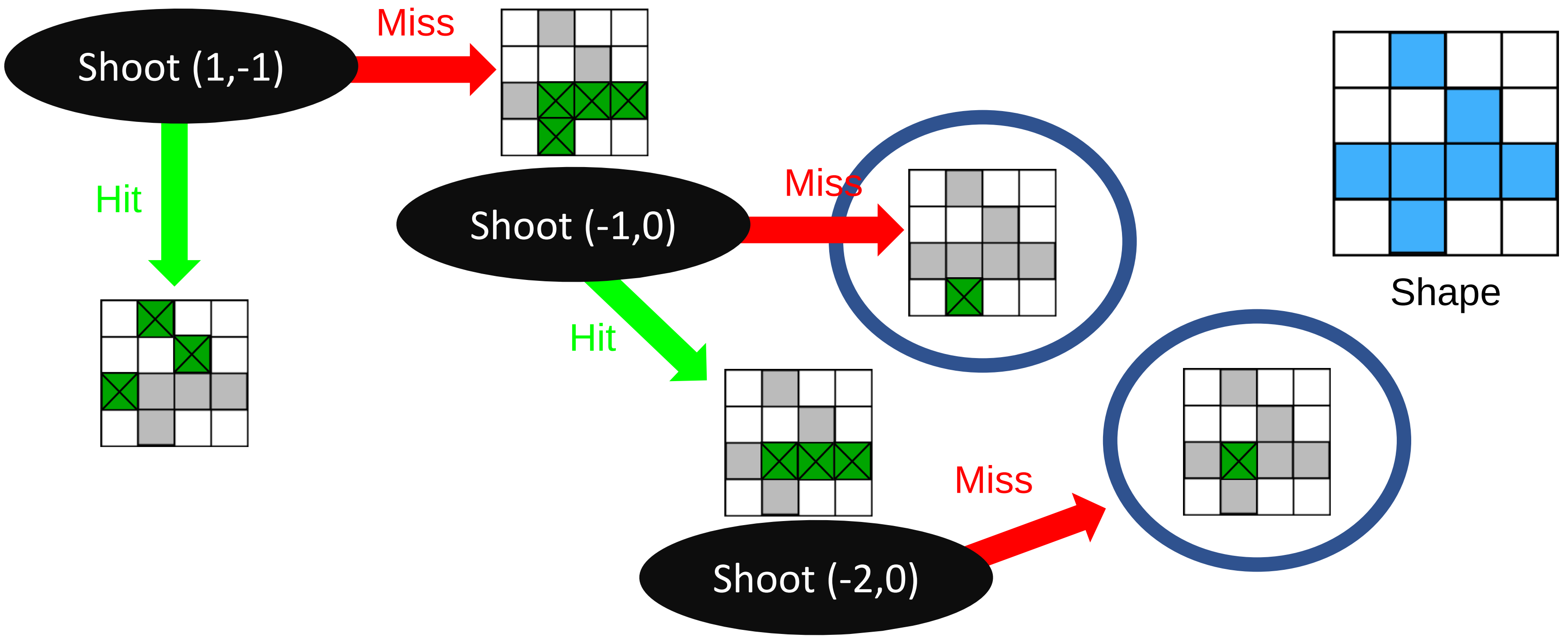
Shape

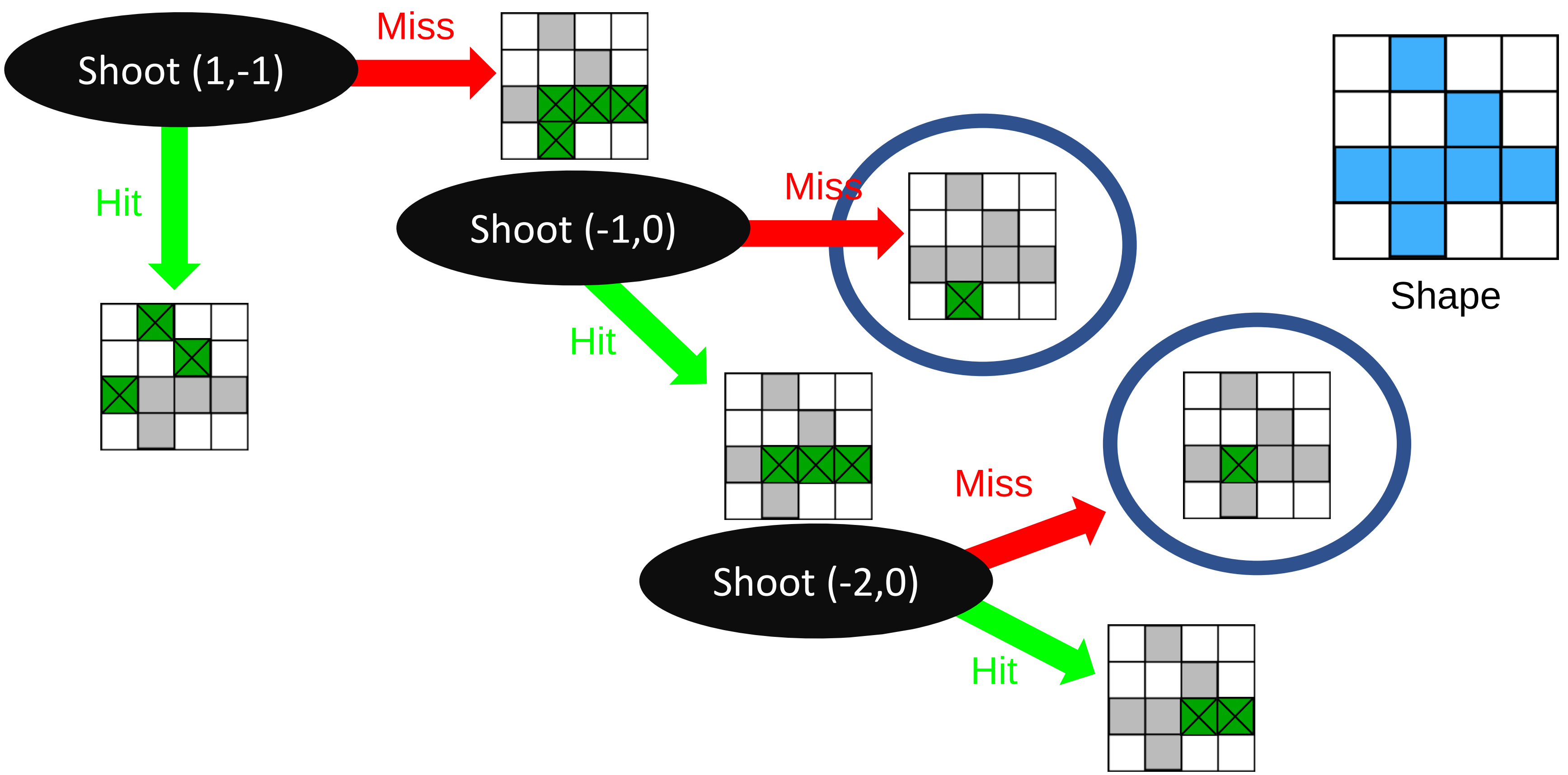

Miss
Shoot (1,-1)
Hit
Shoot (-1,0)
Miss
Shape

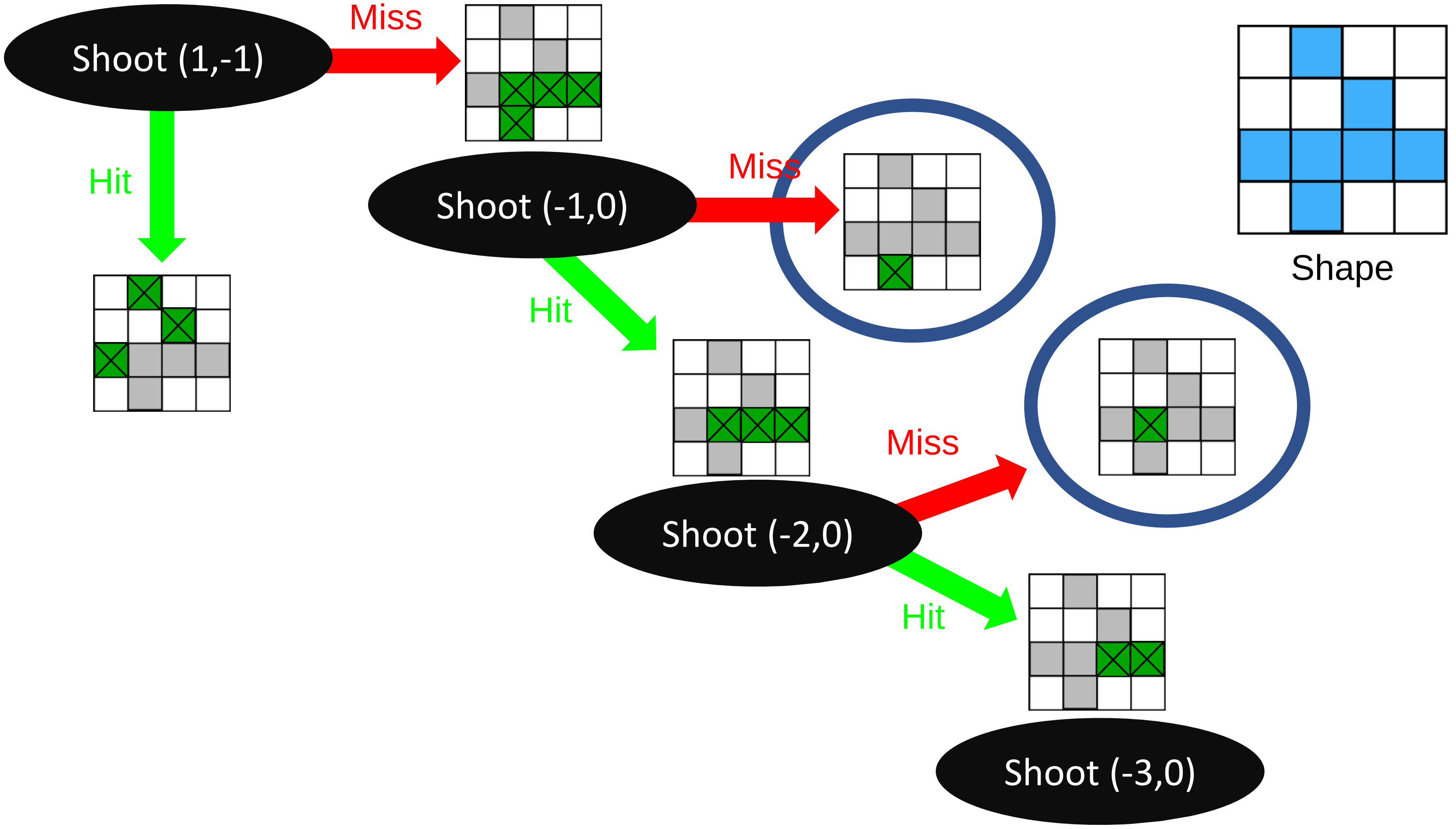



Shape

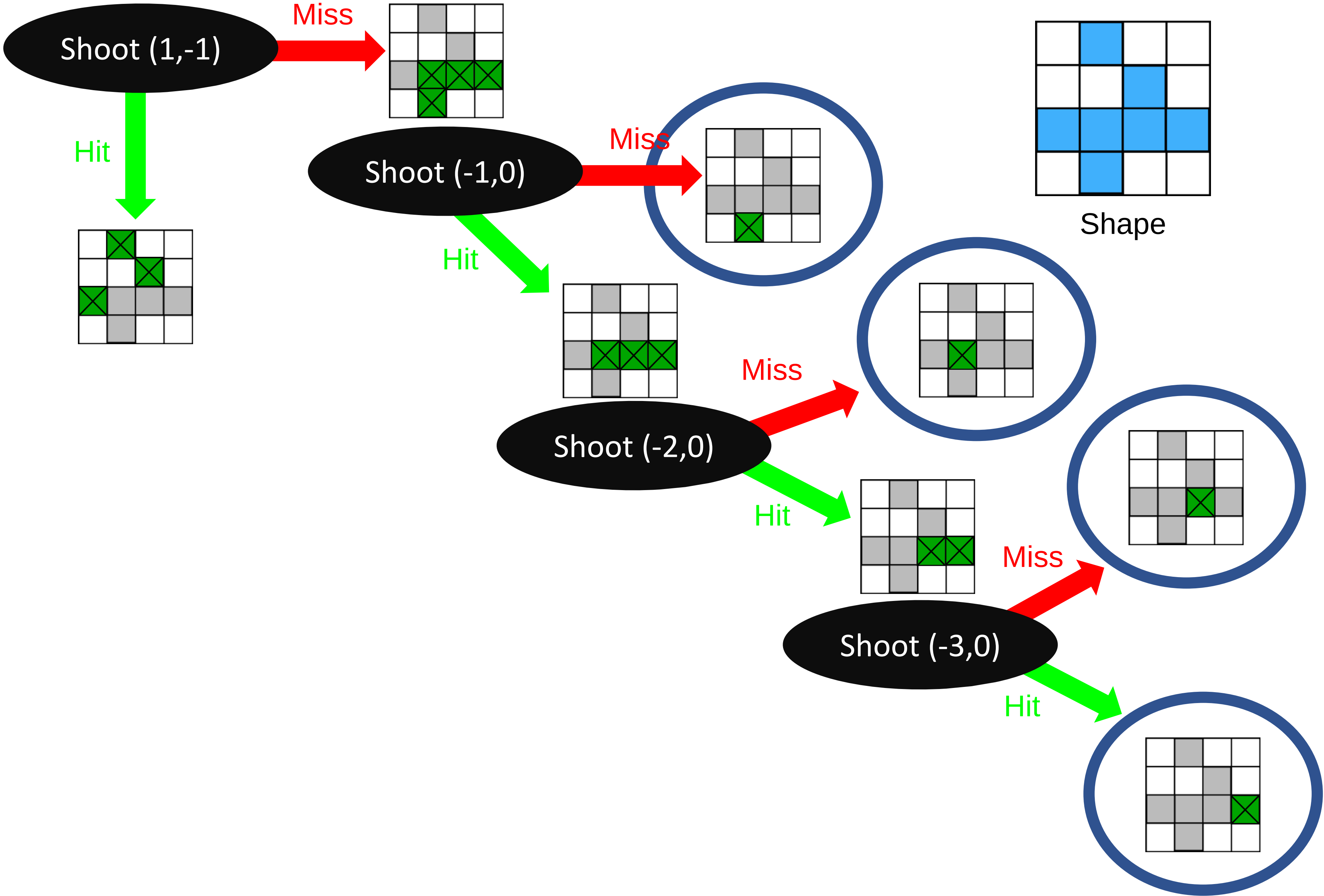

Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shoot (-2,0)
Shape

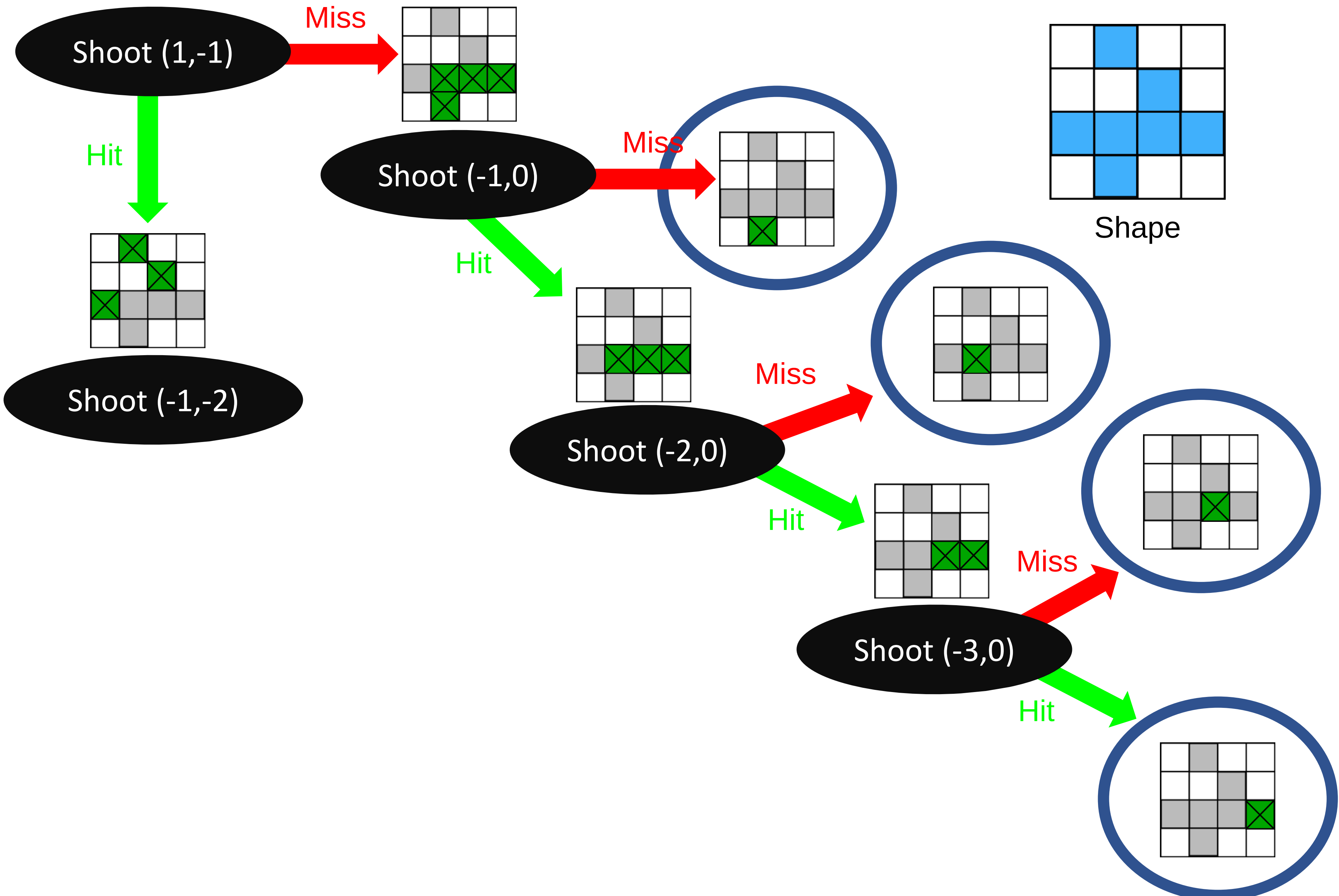

Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shoot (-2,0)
Miss
Shape

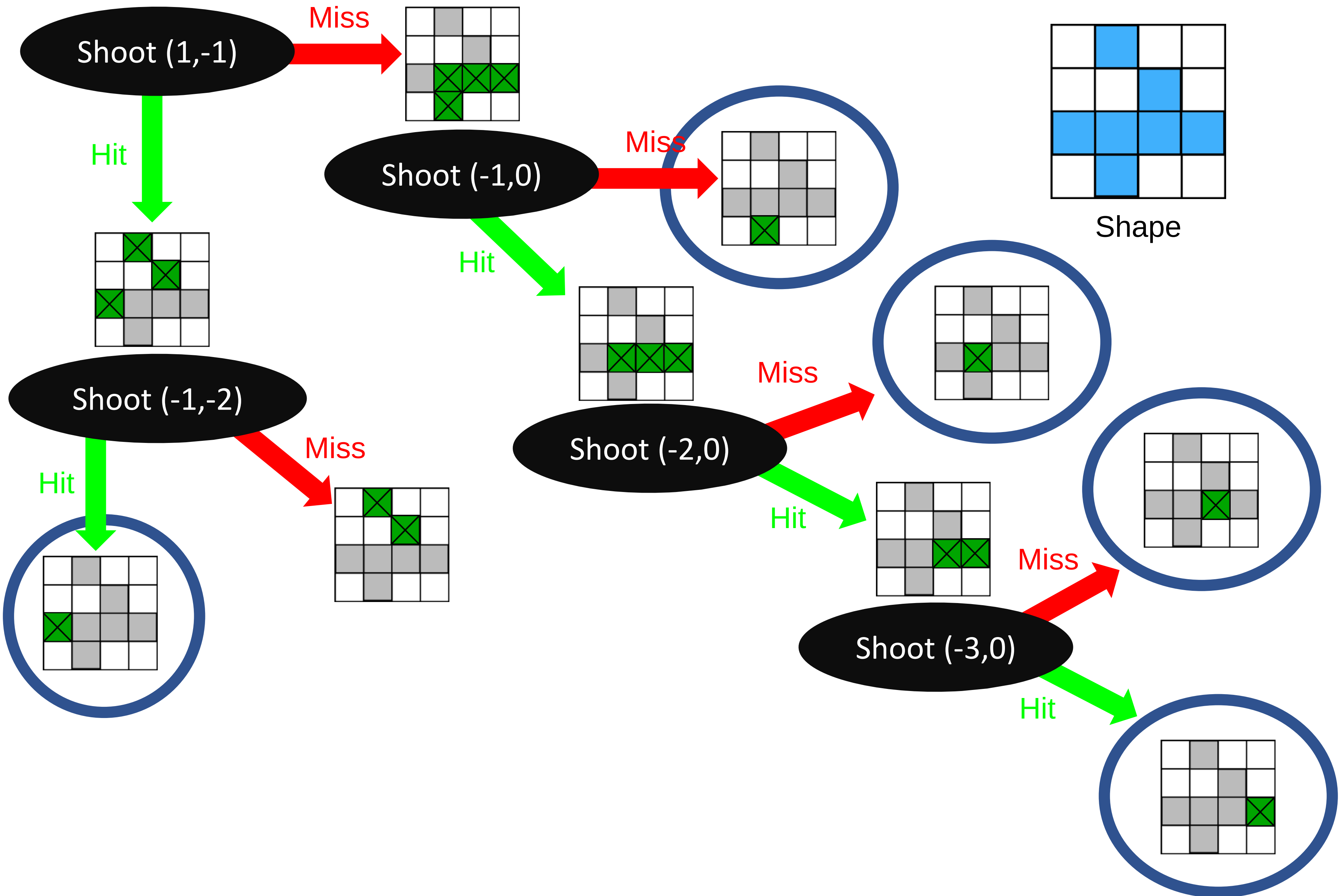

Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shoot (-2,0)
Miss
Hit
Shape

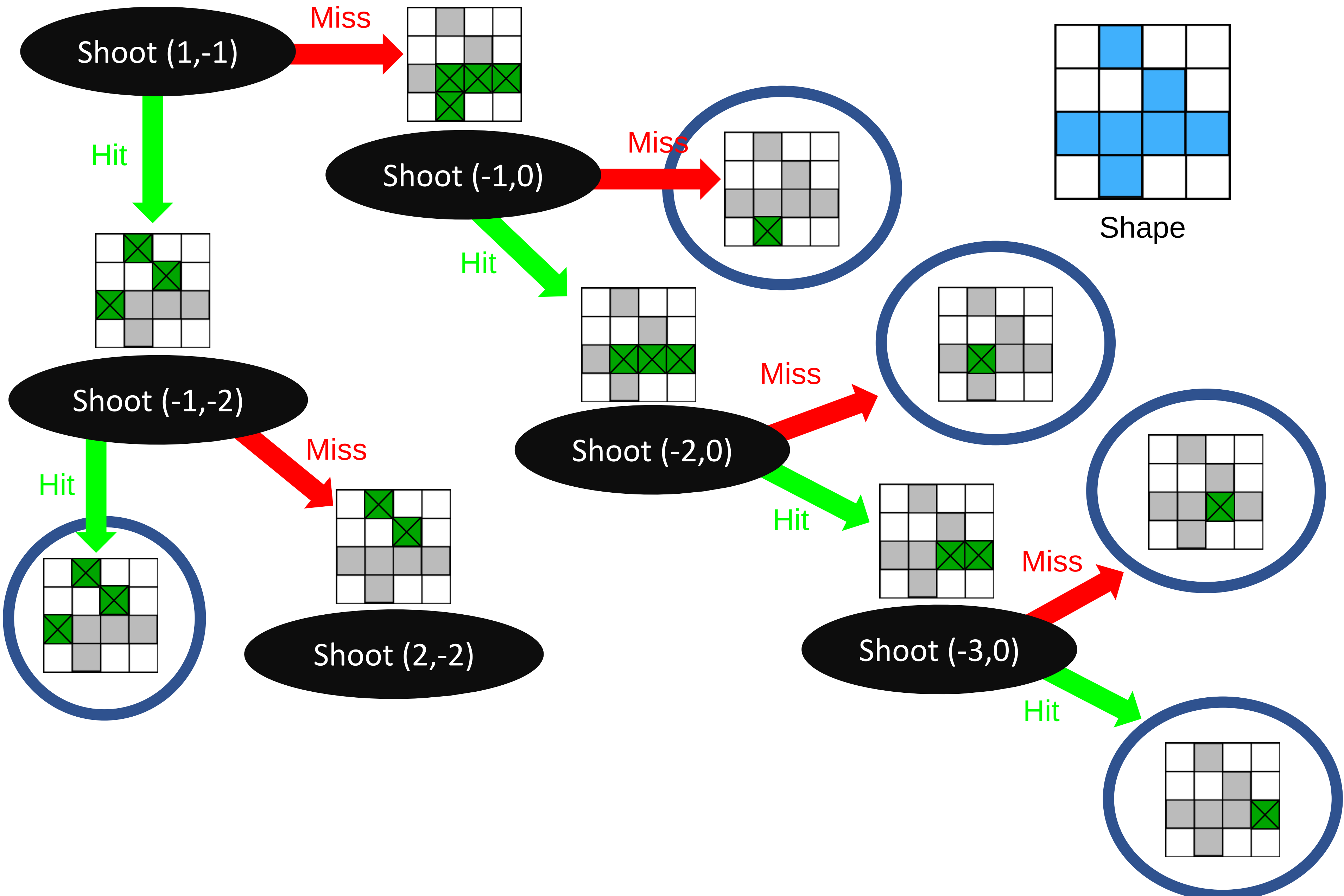

Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shoot (-2,0)
Miss
Hit
Shoot (-3,0)
Shape

Example 5

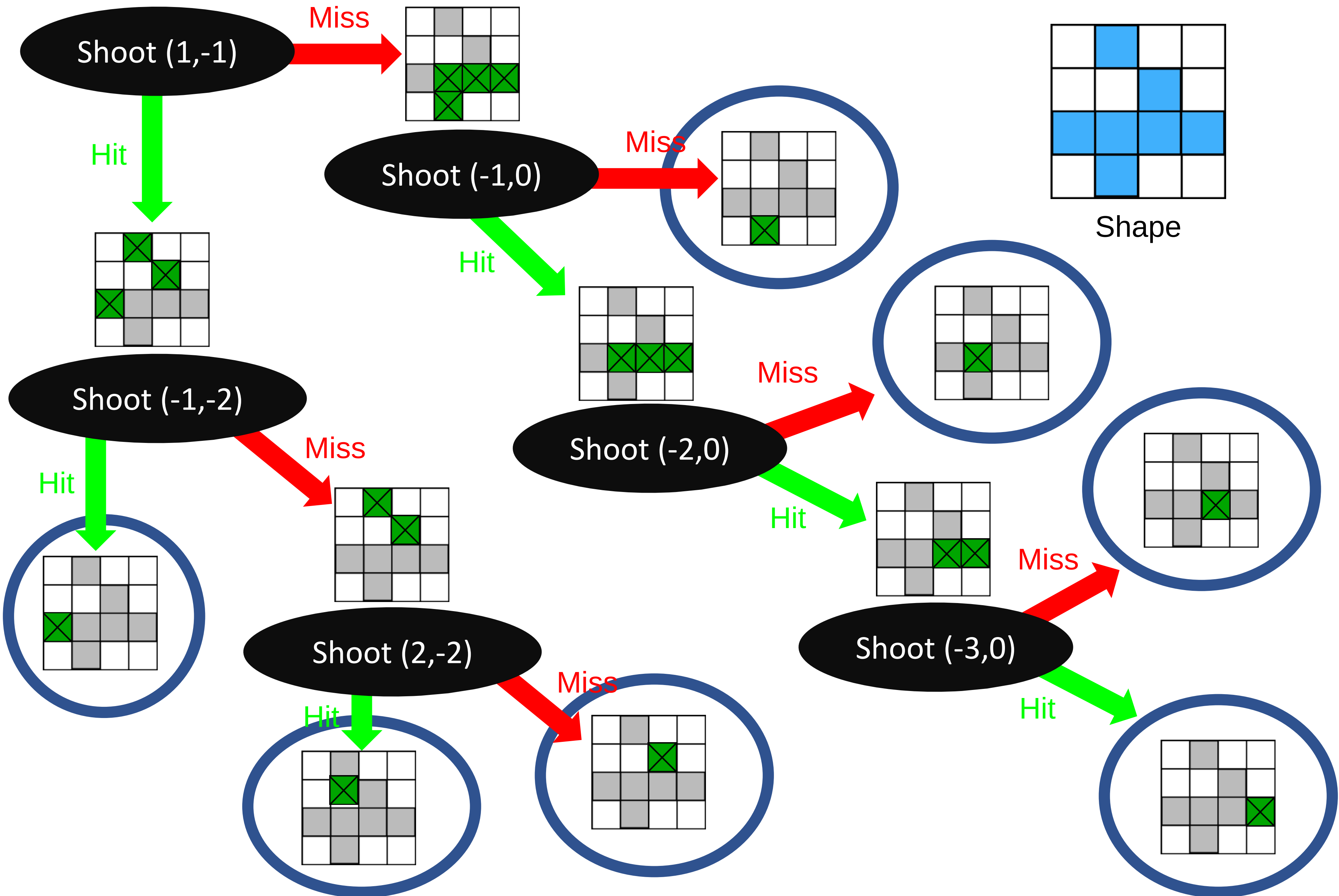

Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shoot (-2,0)
Miss
Hit
Shoot (-3,0)
Miss
Hit
Shape


Shoot (1,-1)
Miss
Hit
Shoot (-1,-2)
Shoot (-1,0)
Miss
Hit
Shape
Shoot (-2,0)
Miss
Hit
Shoot (-3,0)
Miss
Hit

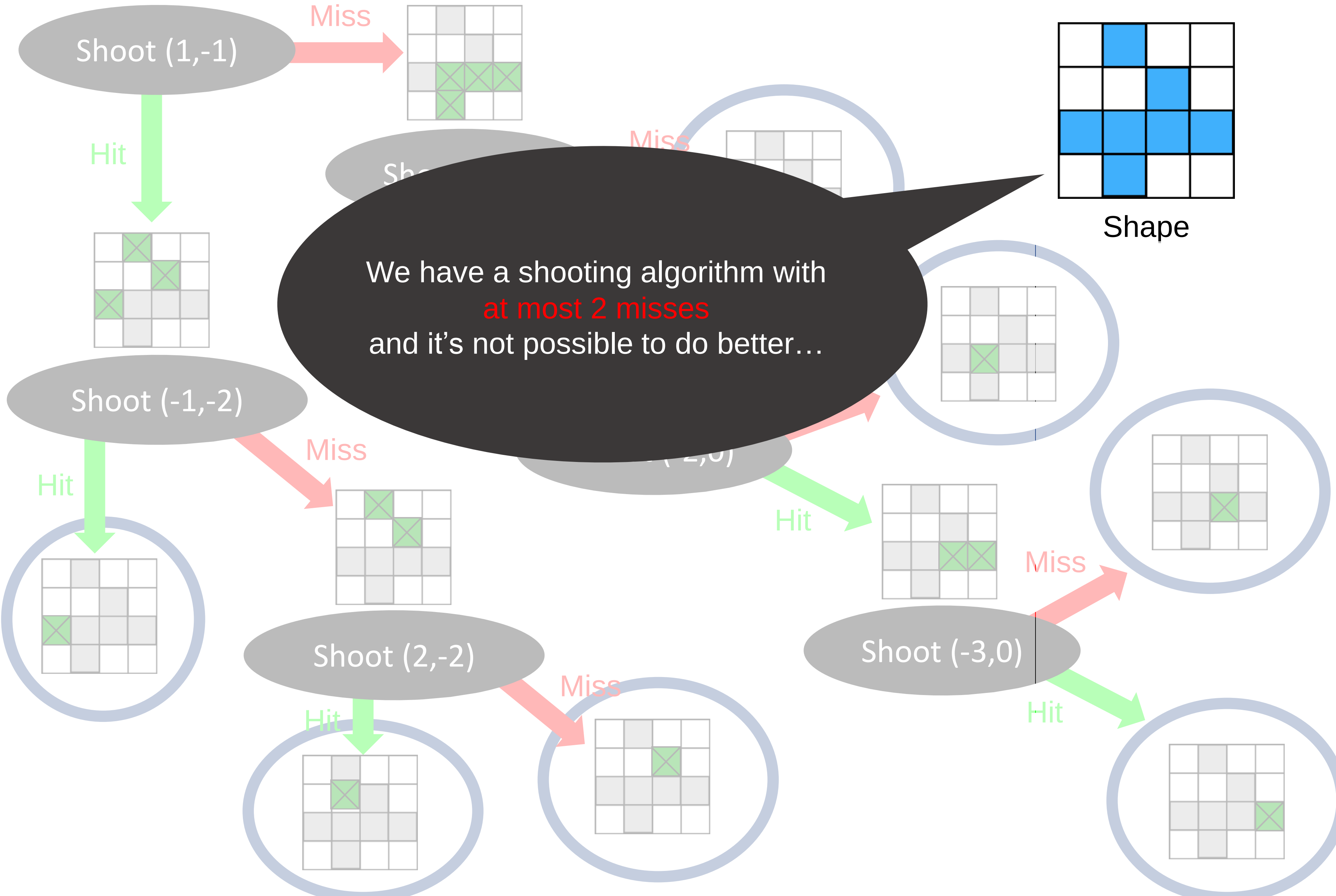

Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shape
Shoot (-1,-2)
Hit
Miss
Shoot (-2,0)
Miss
Hit
Shoot (-3,0)
Miss
Hit


Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shoot (-1,-2)
Hit
Miss
Shoot (2,-2)
Shoot (-2,0)
Miss
Hit
Shoot (-3,0)
Miss
Hit
Shape

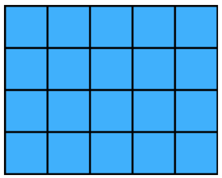
Example 5



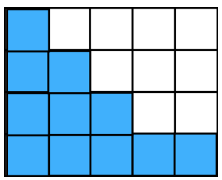
Shoot (1,-1)
Miss
Hit
Shoot (-1,0)
Miss
Hit
Shape
Shoot (-1,-2)
Hit
Miss
Shoot (-2,0)
Miss
Hit
Shoot (2,-2)
Hit
Miss
Shoot (-3,0)
Miss
Hit


Shoot (1,-1)
Miss
Hit
Shoot (-1,-2)
Miss
Hit
Shoot (2,-2)
Hit
Miss
Hit
Shoot (-3,0)
Miss
Hit
Shape
We have a shooting algorithm with
at most 2 misses
and it's not possible to do better…

We have an algorithm with at most 1 miss !



We have an algorithm with at most 2 misses !



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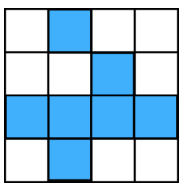

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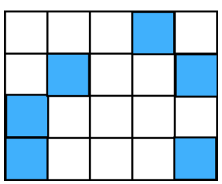
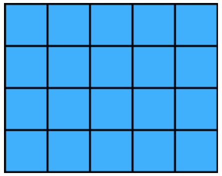
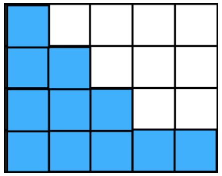


We have an algorithm with at most 5 misses !

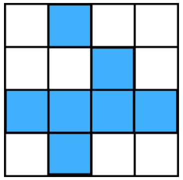
We have an algorithm with at most 1 miss !



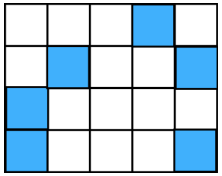
We have an algorithm with at most 2 misses !



We have an algorithm with at most 2 misses !



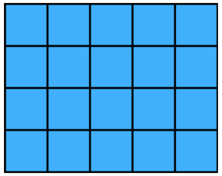
We have an algorithm with at most 2 misses !



We have an algorithm with at most 5 misses !

And we cannot do better…

We have an algorithm with at most 1 miss !



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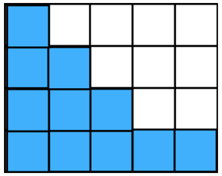

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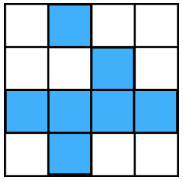

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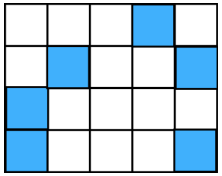
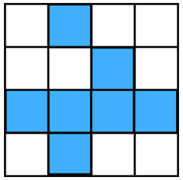


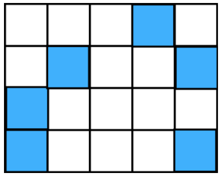
We have an algorithm with at most 5 misses !

And we cannot do better…

This integer is the *battleship complexity* of each shape



We have an algorithm with at most 2 misses !



We have an algorithm with at most 5 misses !

And we cannot do better…

This integer is the *battleship complexity* of each shape

Definition

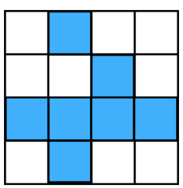
The *battleship complexity* of a shape is a minimum of a maximum:

it is the minimum among all shooting algorithms

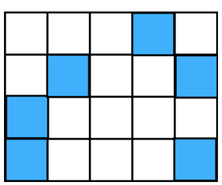
of the maximum number of misses that we can get with this algorithm

among all positions of the ship.

Complexity (S)= $\mathrm{Min}_{\text{shooting algorithm}} (\mathrm{Max}_{\text{ship positions}} (\text{number of misses}))$



We have an algorithm with at most 2 misses !



We have an algorithm with at most 5 misses !

And we cannot do better…

This integer is the *battleship complexity* of each shape

Plan

I Problem Statement

II Shooting Algorithms

III Results

IV Proofs

Plan

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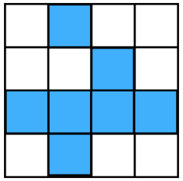
$$\text{Complexity}(S) = \text{Min}_{\text{shooting algorithm}} \left(\text{Max}_{\text{ship positions}} \left(\text{number of misses}\right)\right)$$

Is it easy to compute ?



Complexity= 2

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The *battleship complexity* of a shape is a minimum of a maximum:

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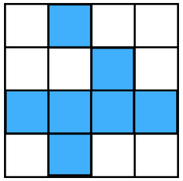
among all positions of the ship.

$$\text{Complexity}(S) = \text{Min}_{\text{shooting algorithm}} \left(\text{Max}_{\text{ship positions}} (\text{number of misses})\right)$$

Is it easy to compute ?

NO!!!!! (max for all shooting algorithms!)



Complexity= 2

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The *battleship complexity* of a shape is a minimum of a maximum:

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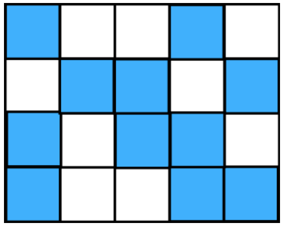
among all positions of the ship.

Complexity(S)= $\mathrm{Min}_{\text{shooting algorithm}}\,(\mathrm{Max}_{\text{ship positions}}\,(\text{number of misses}))$

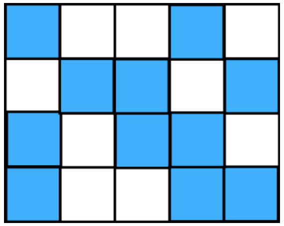
Is it easy to compute ?

NO!!!!! (max for all shooting algorithms!)

Any shooting algorithm provides an upper bound of the Battleship Complexity…



A shape *S* with *n* squares

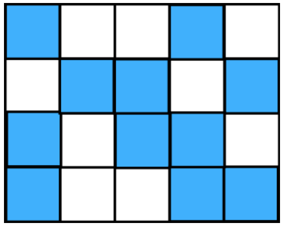


A shape *S* with *n* squares

Bound 1

For any shape

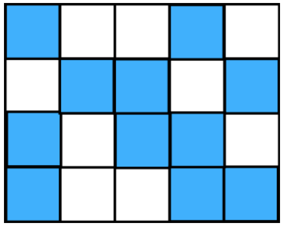
Complexity(S) ≤ n-1



A shape *S* with *n* squares

Bound 1
For any shape
Complexity(S) ≤ n-1

For parallelogram-free shapes, we have
Complexity(S)=n-1



A shape *S* with *n* squares

Bound 1
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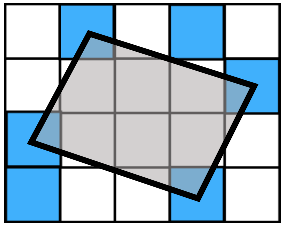
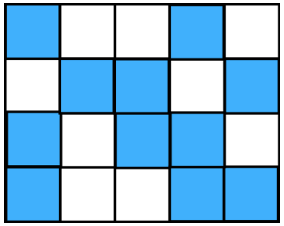


Non Parallelogram-free shape

There exists 4 distinct points u,v,s,t in S with v-u=t-s



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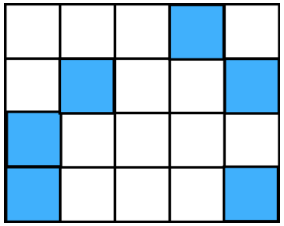
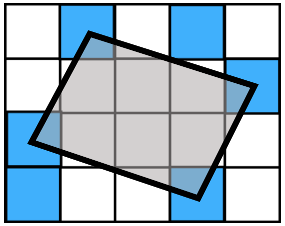


Parallelogram-free shape



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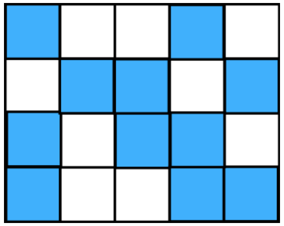

A shape *S* with *n* squares

Bound 1

For any shape

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Bound 1
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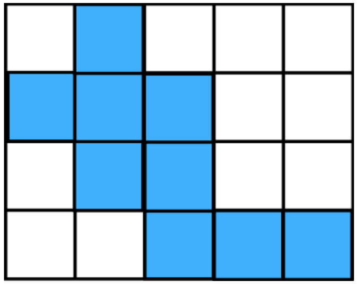
Bound 2
For HV-convex polyominoes
complexity(S) =O(log(n))



A HV-convex polyomino

It is a 4-connected,
horizontally and vertically convex shape

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Bound 3
For digital convex polyominoes
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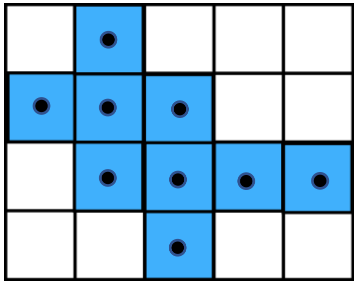

A digital convex shape

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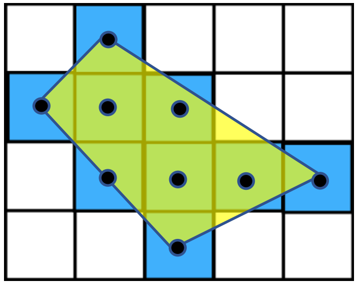

A digital convex shape

Plan

I Problem Statement

II Shooting Algorithms

III Results

IV Proofs

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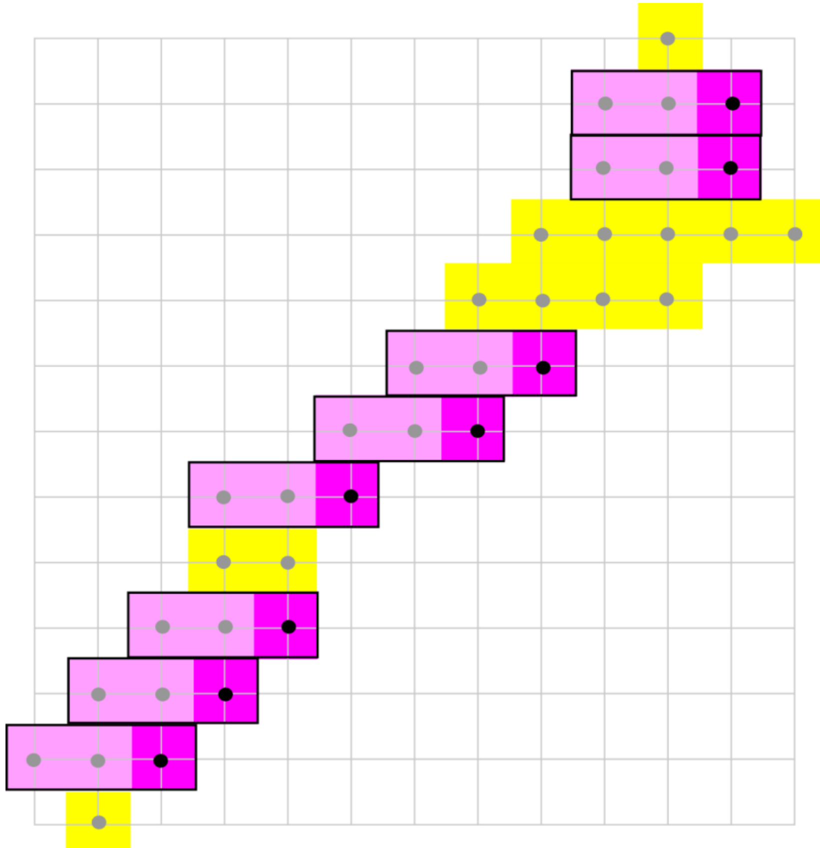
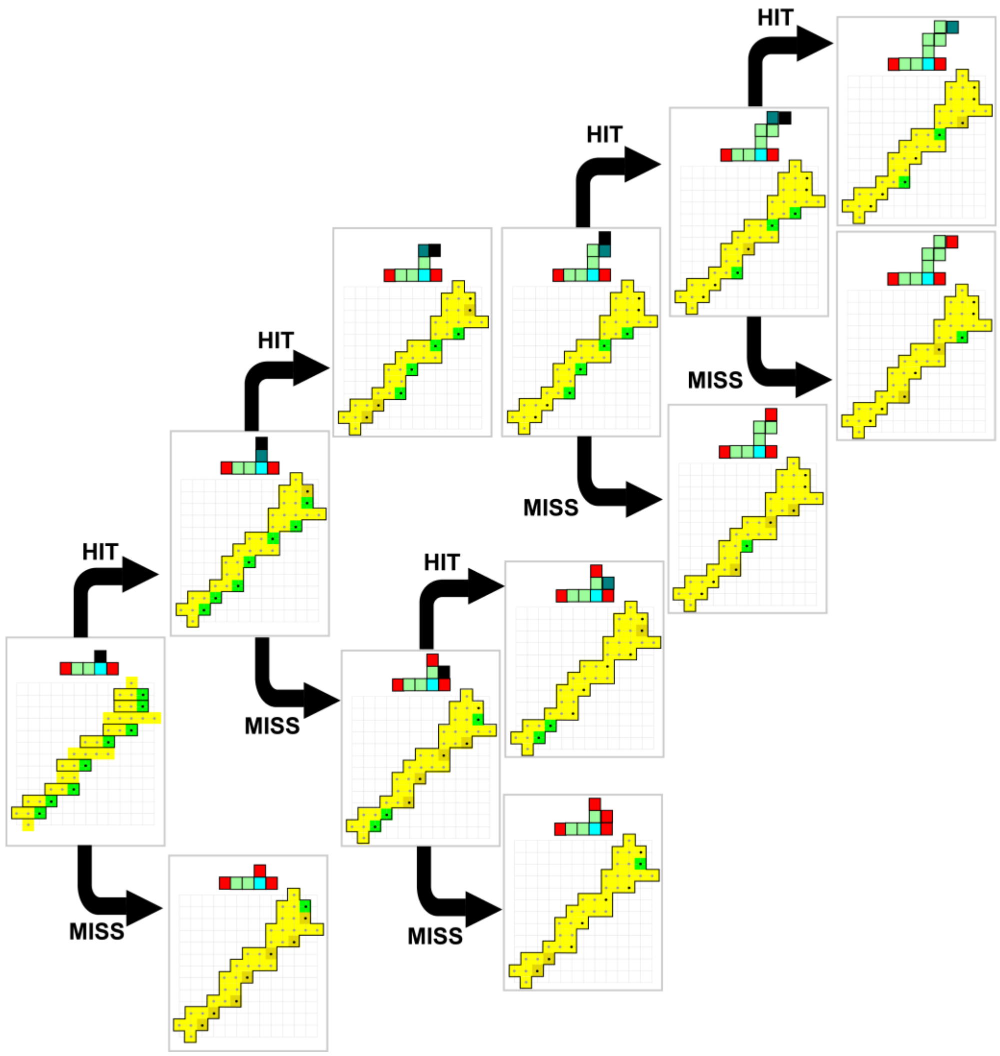


We use a property of monotonicity of HV-convex polyominoes…

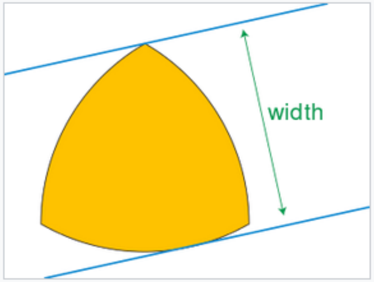


We build a staircase shooting algorithm with at most O(log(n)) misses

Blaschke–Lebesgue theorem

From Wikipedia, the free encyclopedia

In plane geometry the **Blaschke–Lebesgue theorem** states that the Reuleaux triangle has the least area of all curves of given constant width.[1] In the form that every curve of a given width has area at least as large as the Reuleaux triangle, it is also known as the **Blaschke–Lebesgue inequality**.[2] It is named after Wilhelm Blaschke and Henri Lebesgue, who published it separately in the early 20th century.

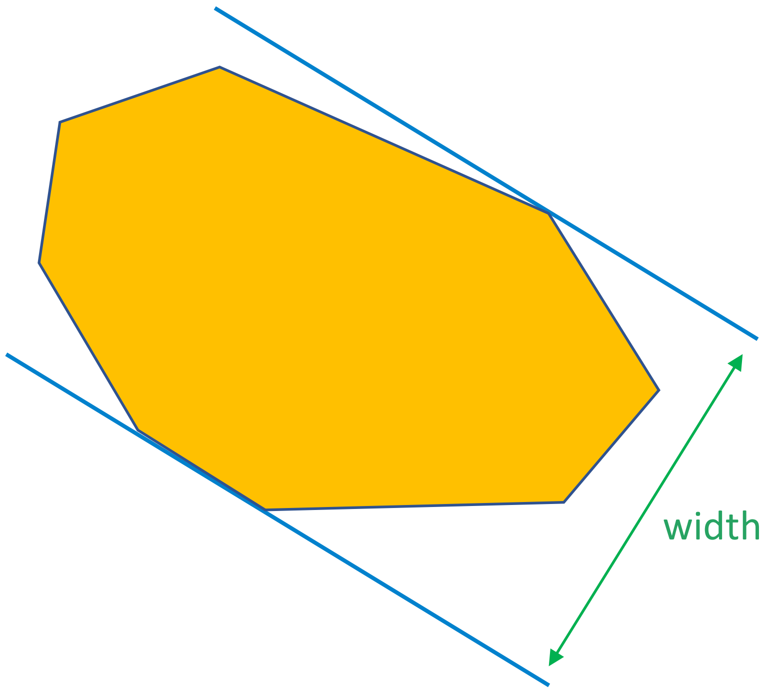


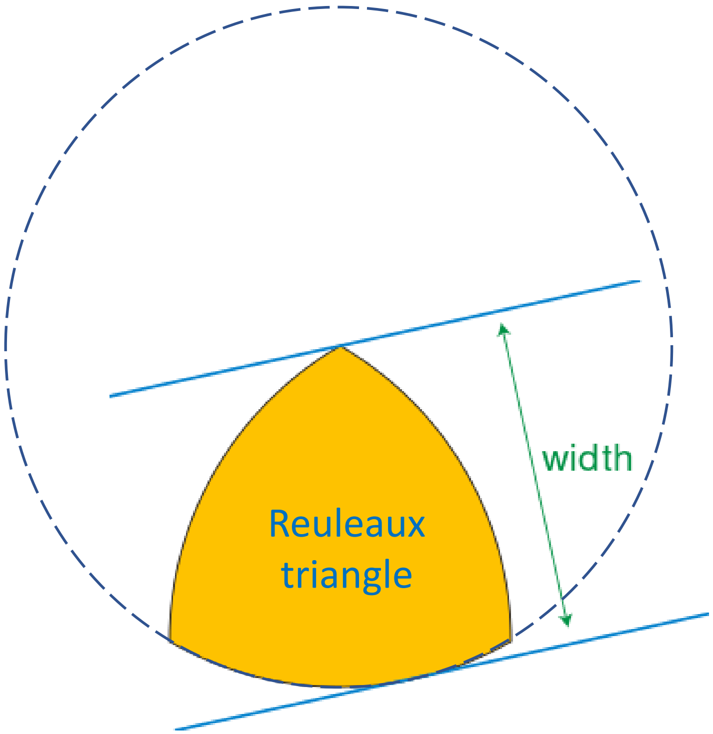
A Reuleaux triangle, a curve of constant width whose area is minimum among all convex sets with the same width

Contents [hide]

Statement [edit]

The width of a convex set K in the Euclidean plane is defined as the minimum distance between any two parallel lines that enclose it. The two minimum-distance lines are both necessarily tangent lines to K, on opposite sides. A curve of constant width is the boundary of a convex set with the property that, for every direction of parallel lines, the two tangent lines with that direction that are tangent to opposite sides of the curve are at a distance equal to the width. These curves include both the circle and the Reuleaux triangle, a curved triangle formed from arcs of three equal-radius



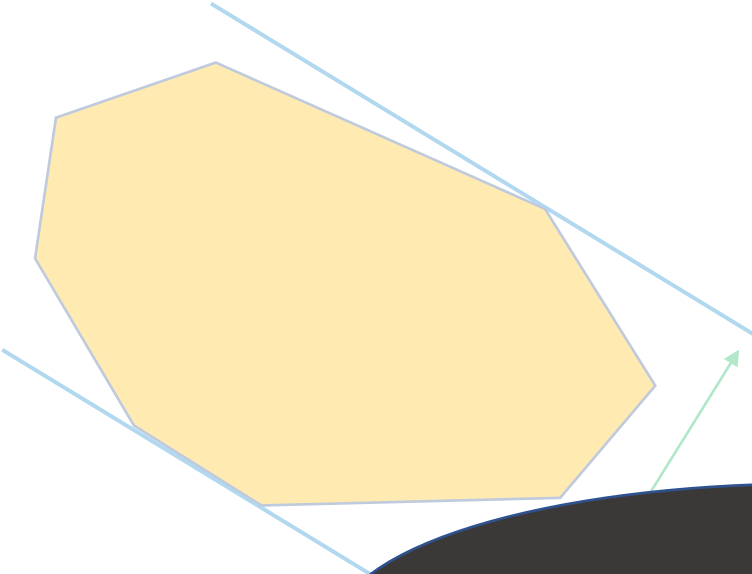


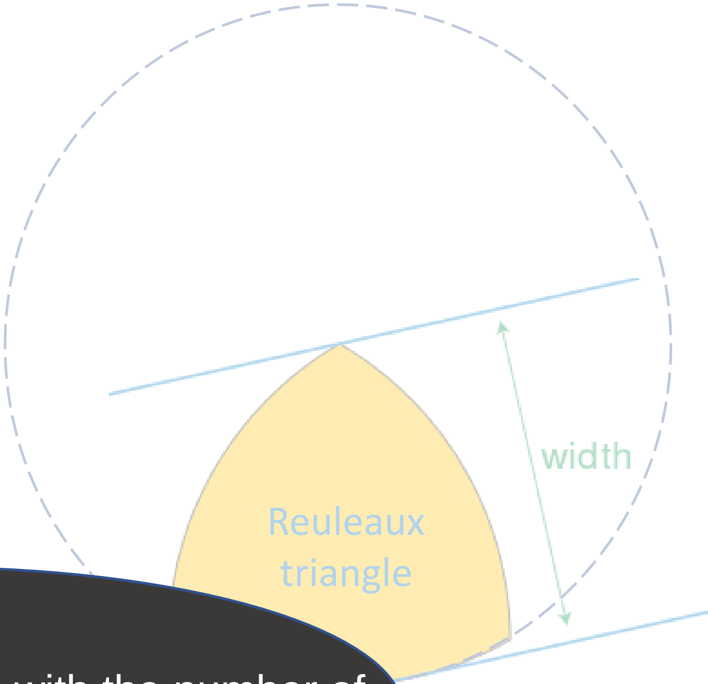
Blaschke-Lebesgue Inequality *(1914)*

The area of a convex shape is bounded by

$$area \geq \frac{1}{2}\left(\pi - \sqrt{3}\right) width^2$$

(Equality is achieved for Reuleaux triangles).





Is there a discrete version with the number of points instead of the area ?

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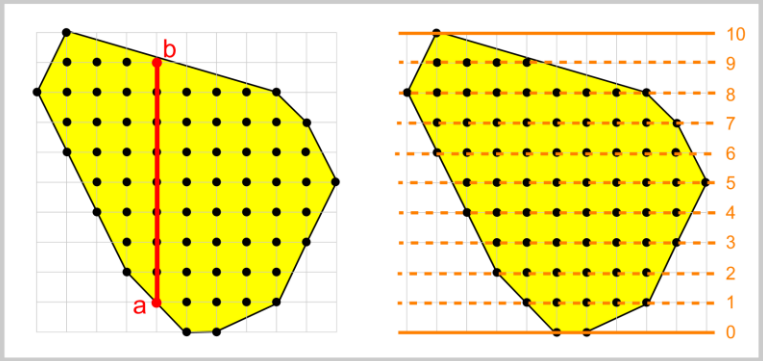
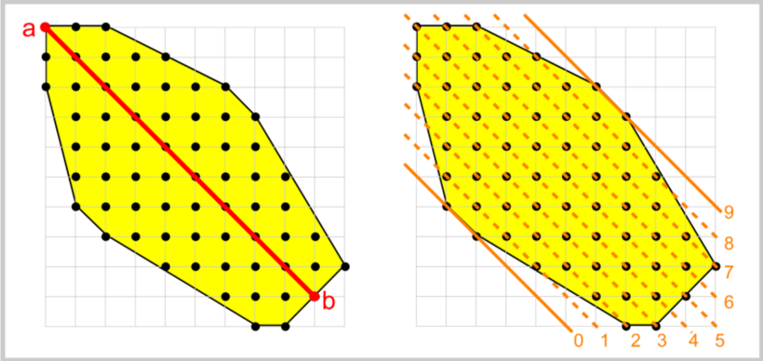


$diam = 9$ $width = 10$



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Pick formula & …

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The number n of a digital convex shape S is bounded by $n \geq \frac{1}{4} width^2 + 2$

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Node

K misses before

Q feasible positions

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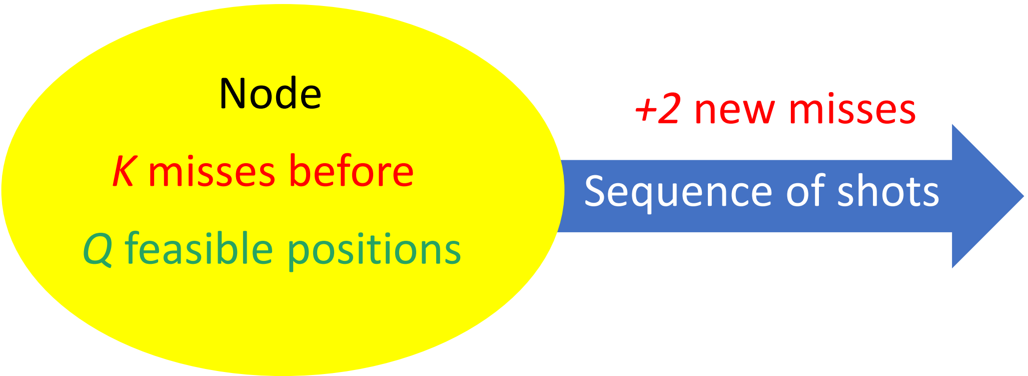

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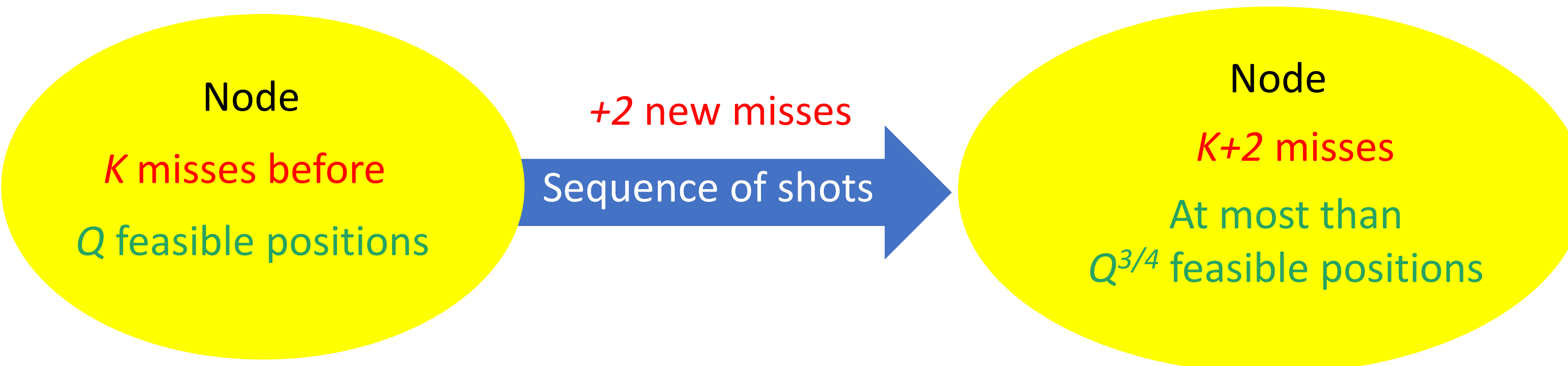

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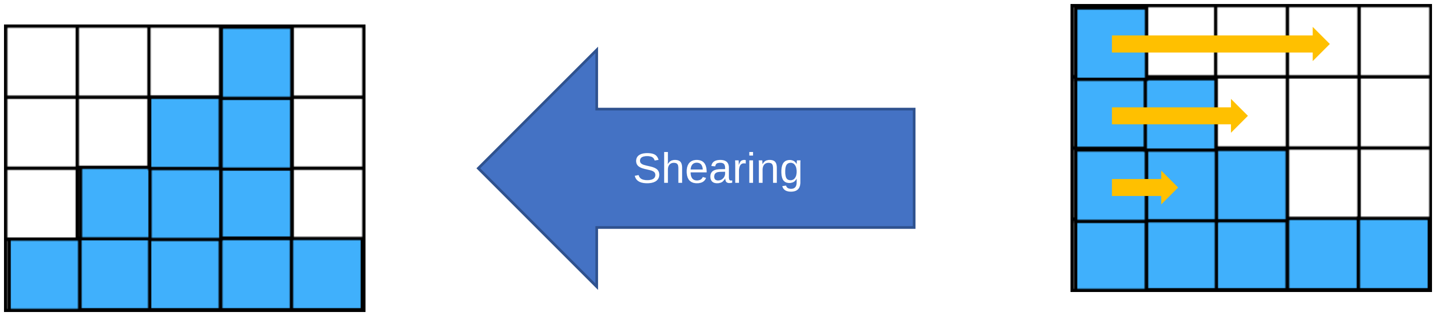
Complexity(A+B) ≤ Complexity(A)+Complexity(B) ?

Thanks a lot for your attention…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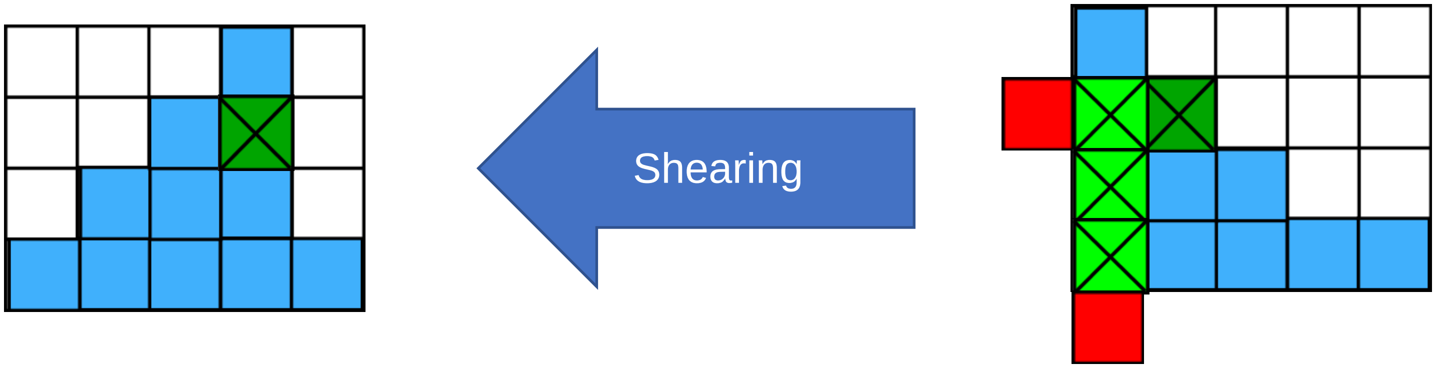
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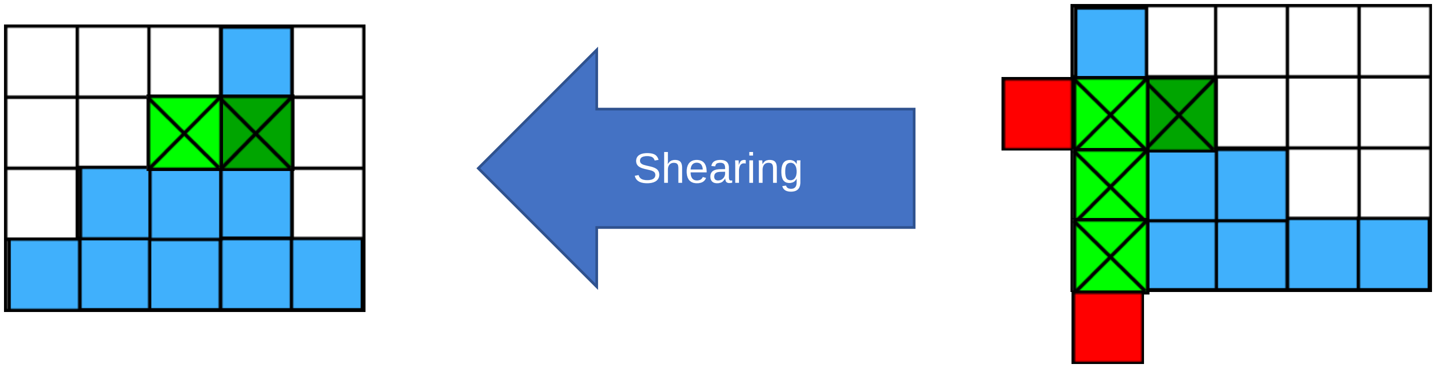
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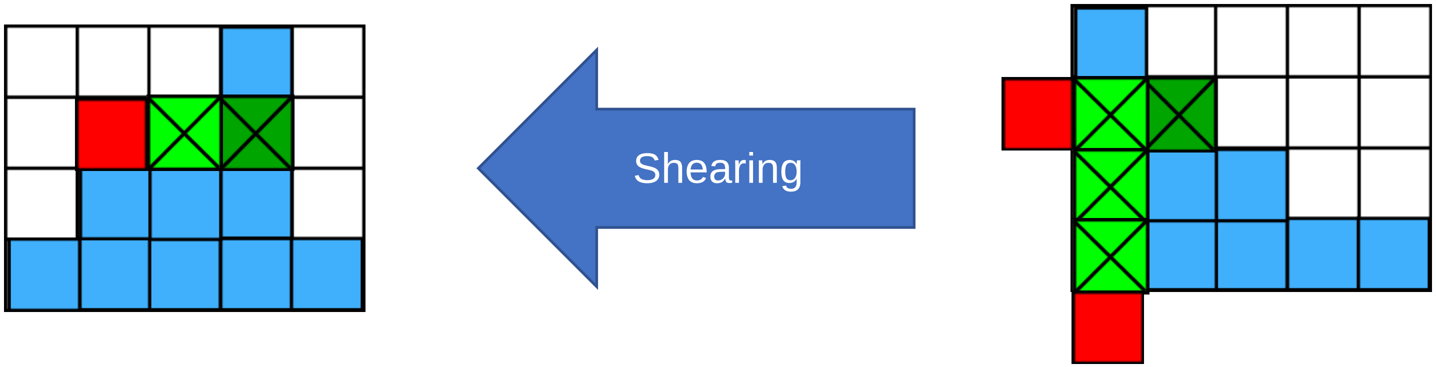
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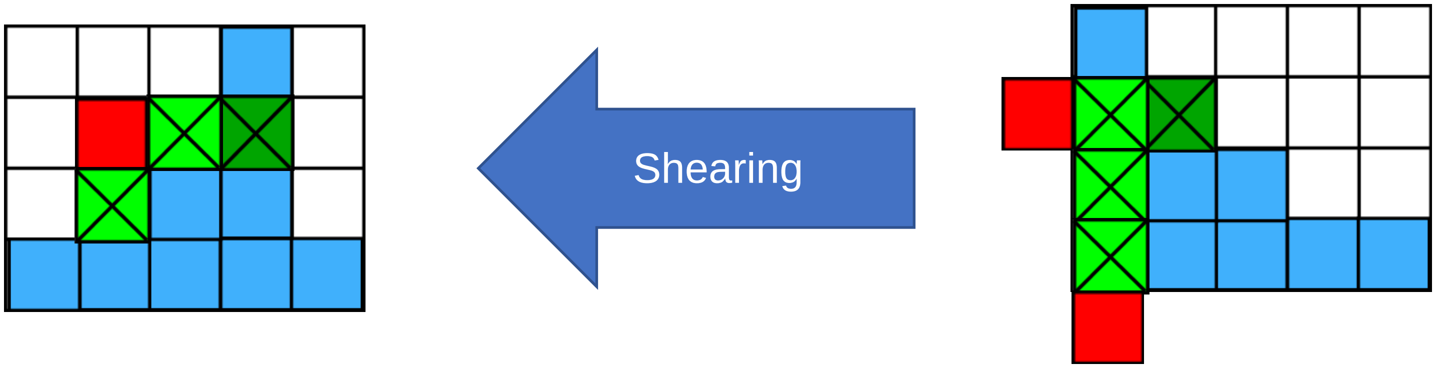
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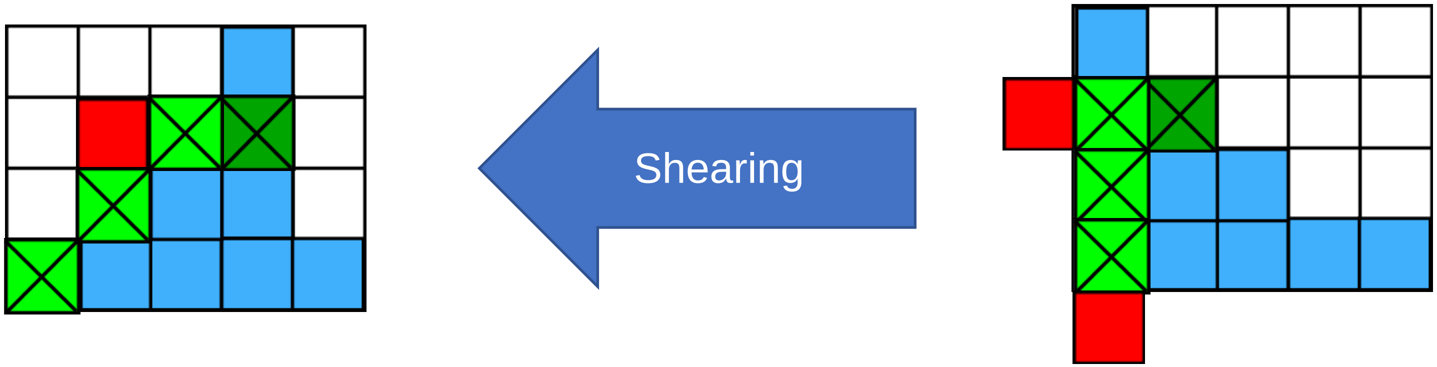
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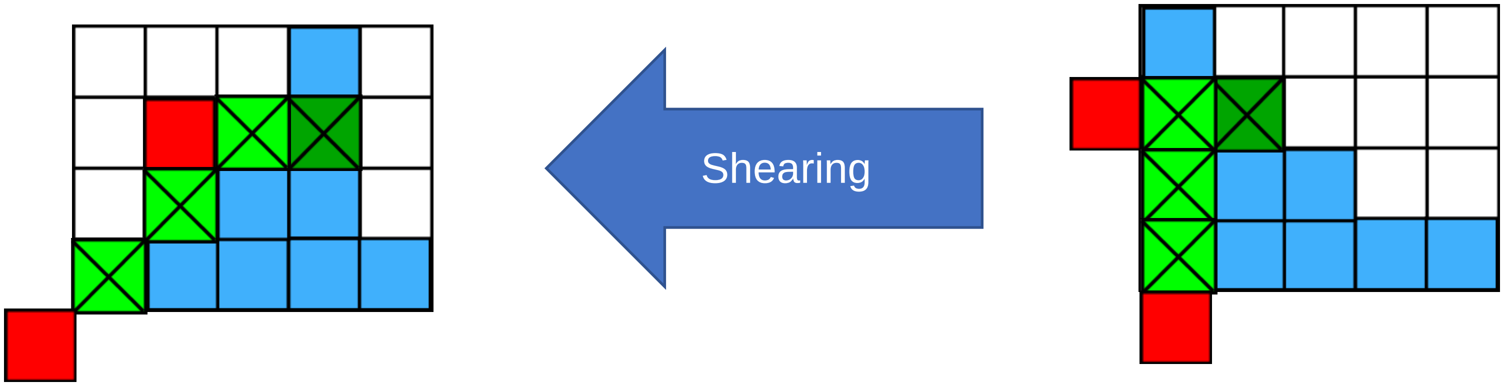

The Battleship complexity is invariant by isomorphisms…