# Introduction to Marxan:
# How Marxan finds good solutions

Delivered by: **Trevor Wiens**

Materials provided by:
PacMARA
info@pacmara.org

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Pacific Marine Analysis & Research Association

Based on materials developed by:
Matthew Watts, Lindsay Kircher, and Hugh Possingham

Applied Environmental Decision Analysis
Commonwealth Environmental Research Facility

The University of Queensland
Australia

# Minimum Reserve Set Problem

Objective of ***minimum set problem*** is:

- Minimise the overall "cost"
- While subject to the "constraint" that all conservation feature targets are met
  (e.g. 20% of each vegetation type)

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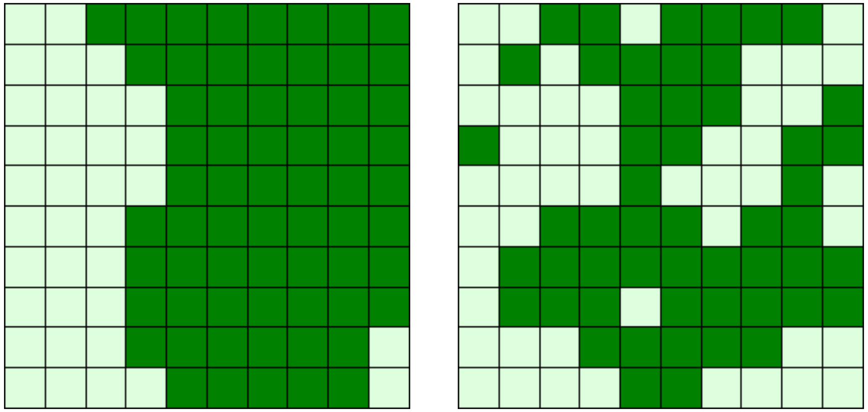
# Simulated annealing

- Identifying a reserve system that meets all these requirements can be **very difficult.**

- For example, deciding which of **100 planning units** would make up the most effective PA system involves choosing between **$2^{100}$** or 1,260,000,000,000,000,000,000,000,000,000 different combinations of units!!

Fortunately, mathematicians have developed ways to identify near-optimal solutions to these type of problems through a process called **simulated annealing.**



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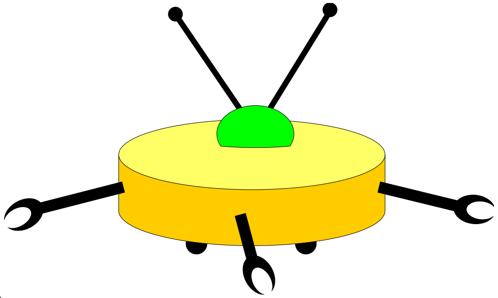
*Source: Bob Smith (DICE)*
http://www.kent.ac.uk/dice/cluz/marxan1.html

# Searching for life on Mars: a simulated annealing analogy

- Life will most likely to be found in low-lying areas

  (Problem of finding the lowest-lying area on Mars using a robot is similar to finding the most efficient set of conservation areas - many alternatives)

- How can simulated annealing help solve this problem?



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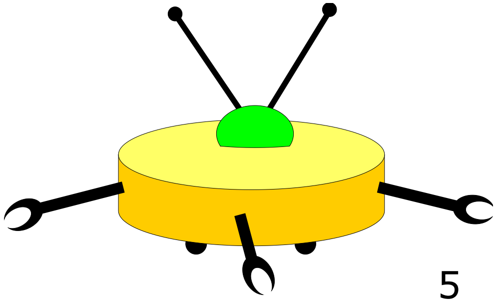
*Source: Bob Smith (DICE)*
http://www.kent.ac.uk/dice/cluz/marxan1.html

# Simulated Annealing – Iterative Improvement

In the case of the robot, iterative improvement involves following the same set of rules to find low-lying areas. The set of rules that the robots follows are:

1) Measure the elevation of the ground directly beneath the robot body
2) Randomly choose an arm and measure the elevation of the ground beneath the arm
3) If the ground beneath the arm is lower than the robot base then move to the point measured by the arm



Source: Bob Smith (DICE)

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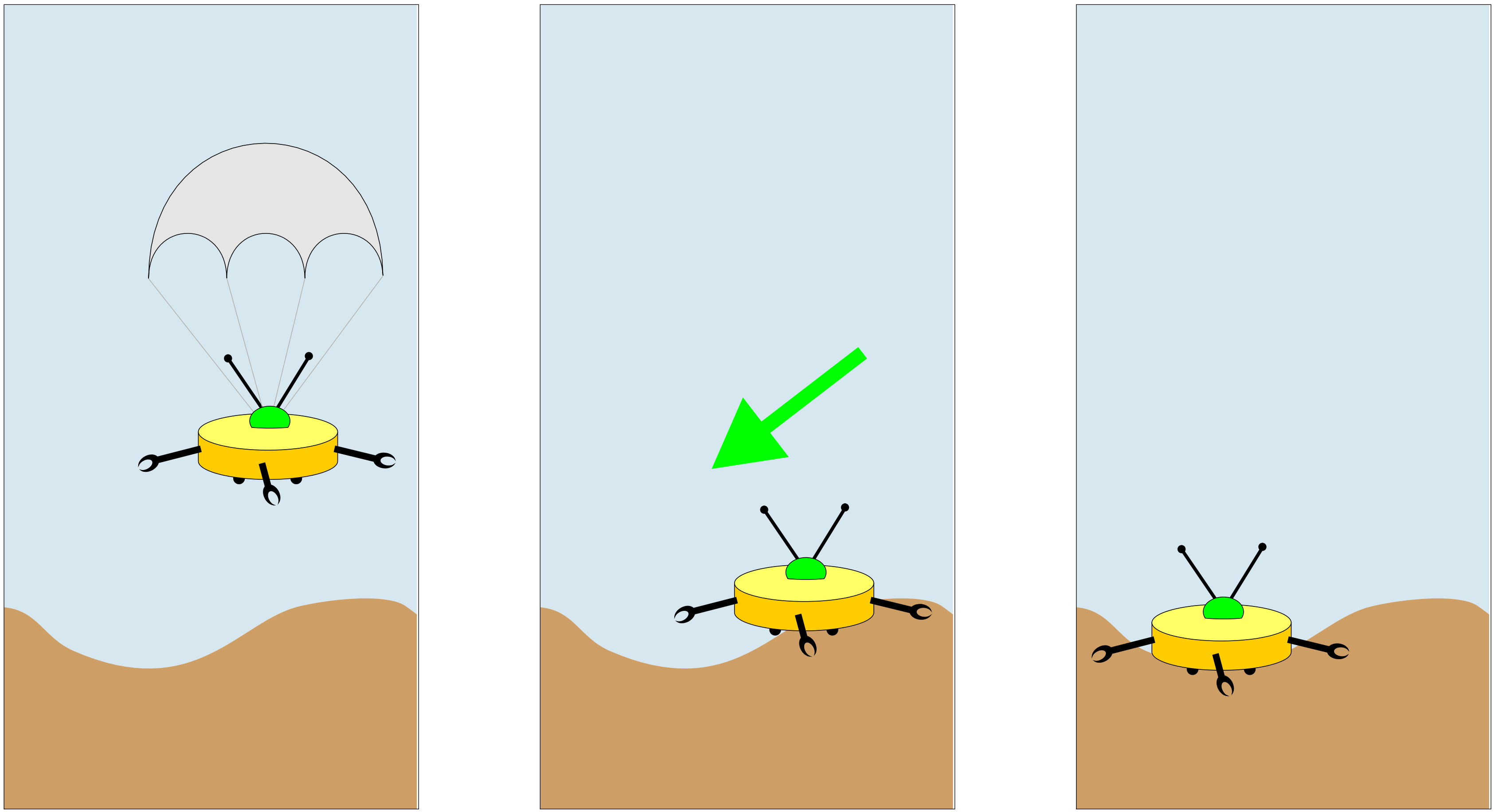
# Simulated Annealing – Let's begin…



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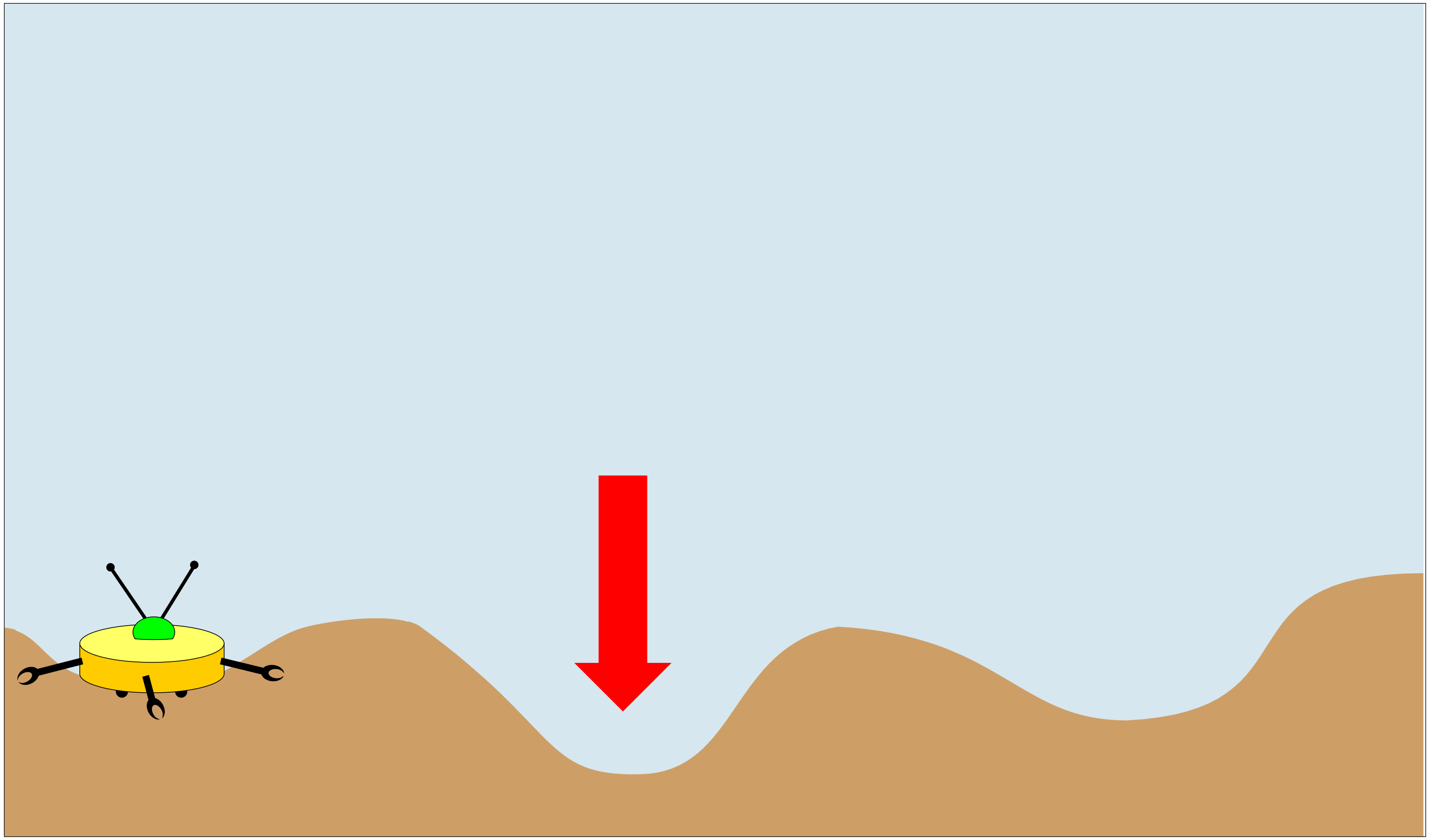
*Source: Bob Smith (DICE)*

# But…this is a flawed strategy as there are lower areas



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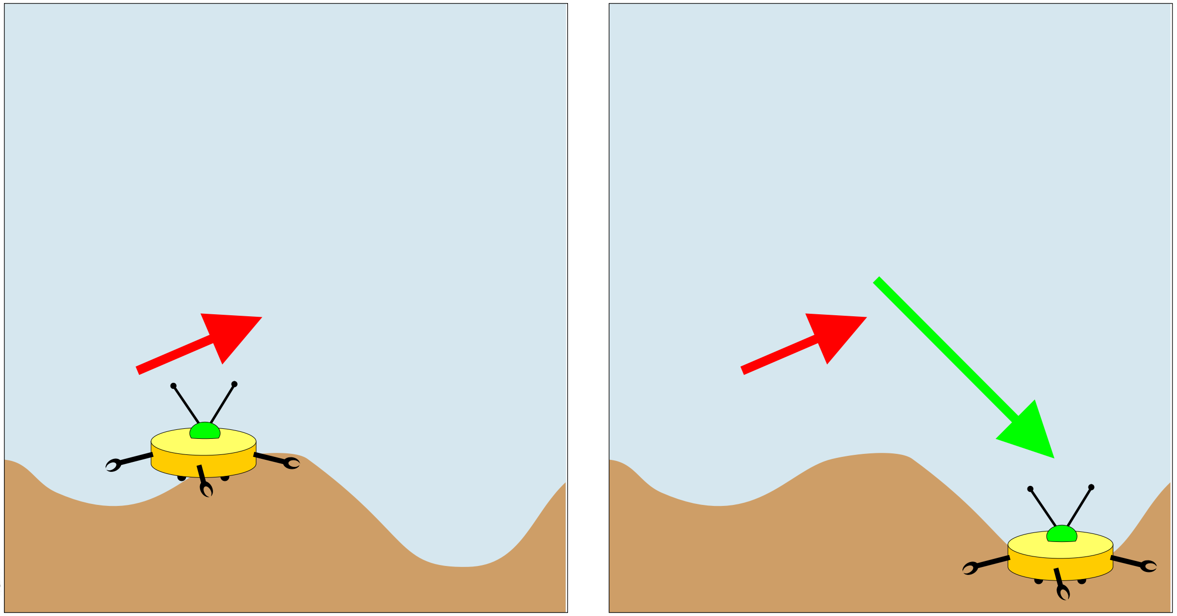
*Source: Bob Smith (DICE)*

# Random backward steps

- Moves up a slope to try to move into neighbouring, lower-lying valleys
- These backward steps are generally more effective just after the robot has landed, so they tend to occur at the beginning of the iterative improvement process (i.e. simulated annealing)



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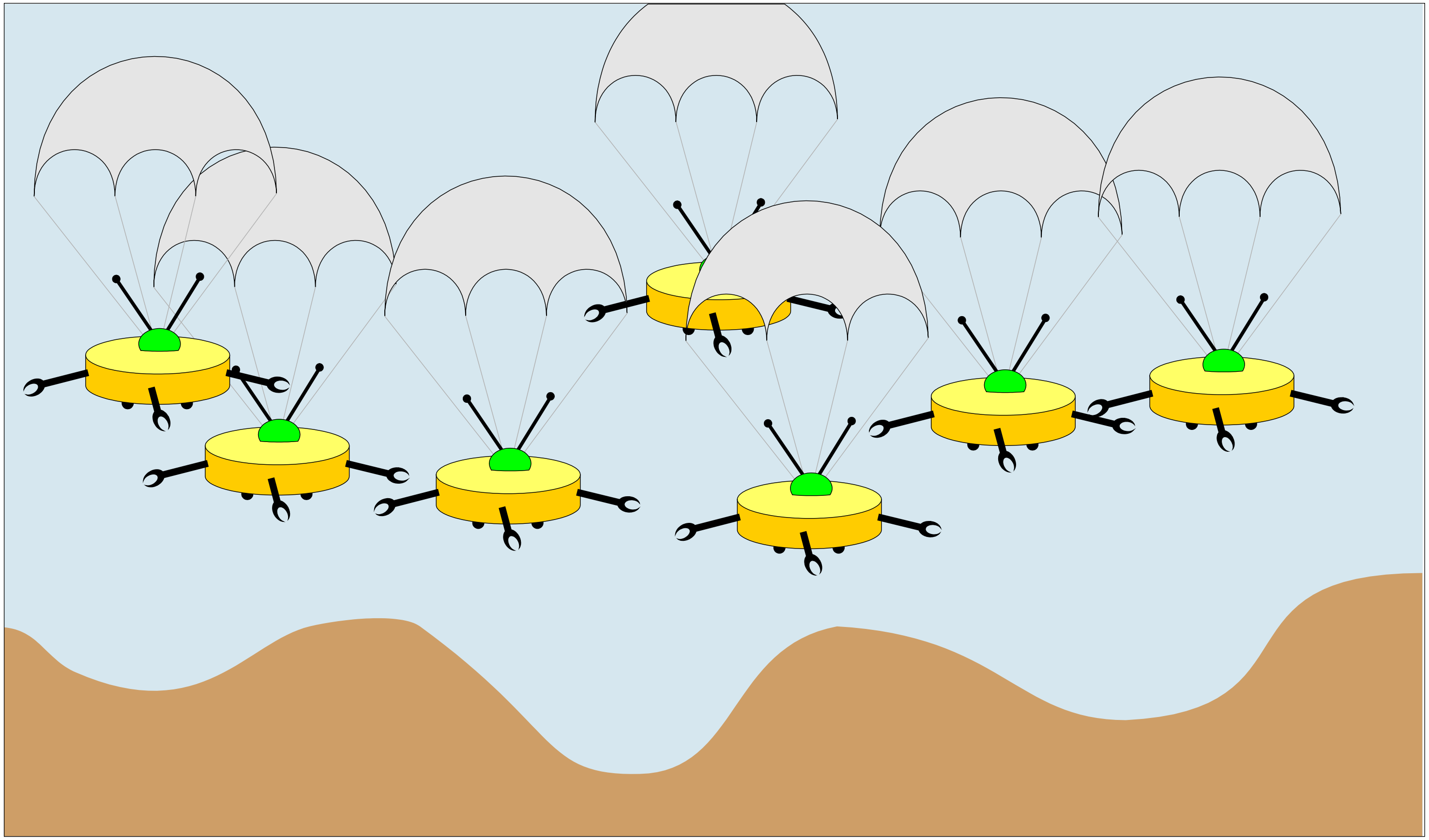
*Source: Bob Smith (DICE)*

# Repetitions



Many robots (runs or solutions) results in many good solutions

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*Source: Bob Smith (DICE)*

# Elevation on Mars ~ Score

Combined Planning Unit Cost (efficiency)

+

Combined Boundary Length (clumping)

+

Combined Target Shortfall

(penalty for not achieving conservation targets)

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# Simulated Annealing in Marxan

## 1) Iterative improvement

MARXAN creates a solution based on randomly selecting a number of planning units. It then improves on this random selection by using iterative improvement, following the next rules:

1. Calculates the cost of the planning solution.
2. Chooses a planning unit at random and includes it or not in the solution (i.e., changes a protected unit to being unprotected or change an unprotected unit to being protected).
3. Calculates the new cost of the new solution
4. If the new solution has a lower cost than the original solution then make the change permanent. Otherwise, do not make the change.

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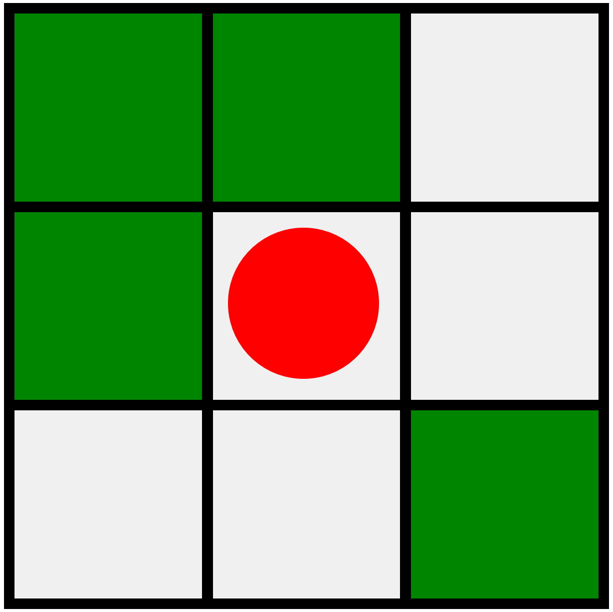
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



Total cost = **32**

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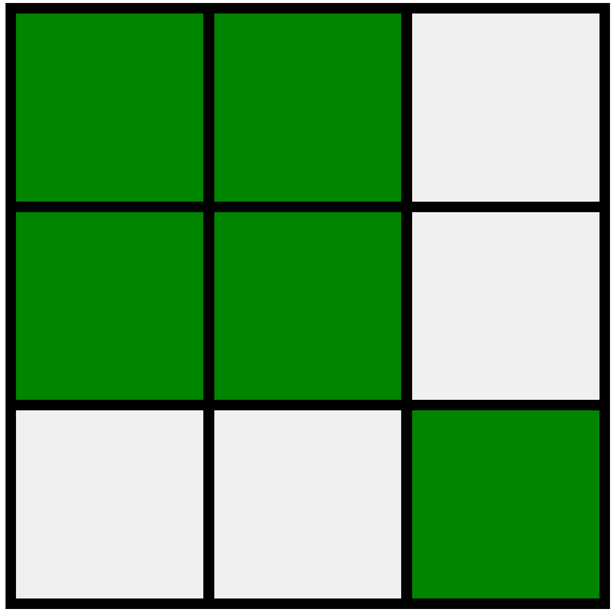
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



**23 < 32**

Total cost = **23**

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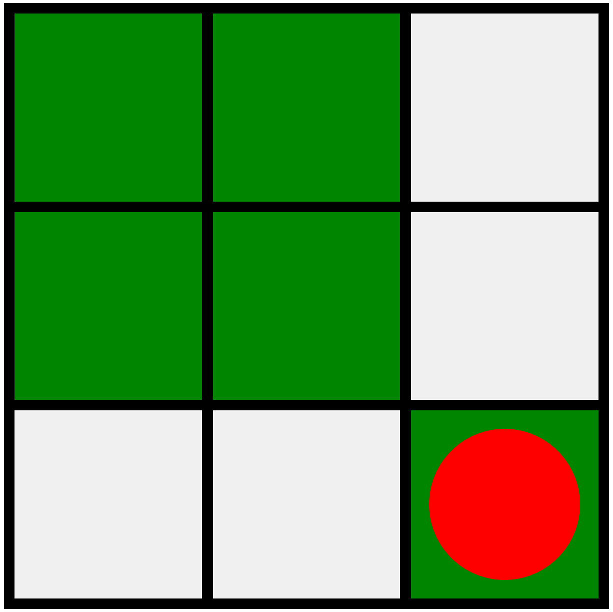
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



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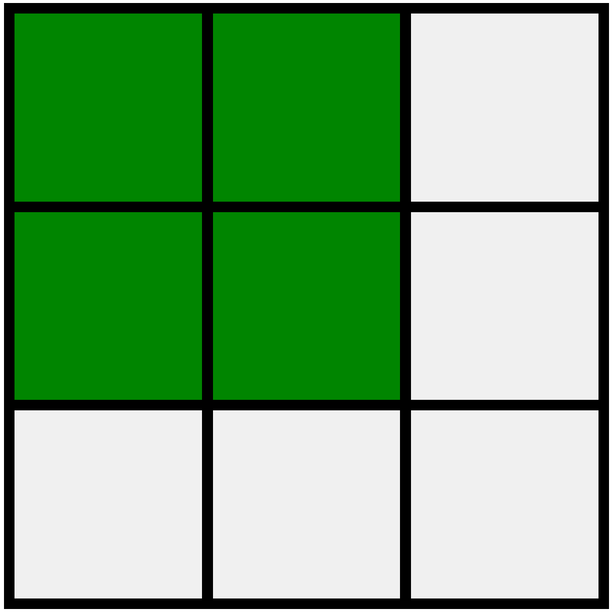
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



✗

**26 > 23**

Total cost = **26**

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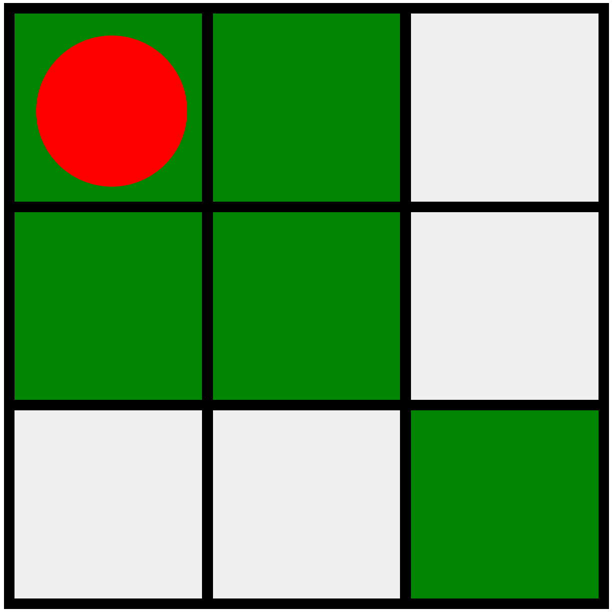
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



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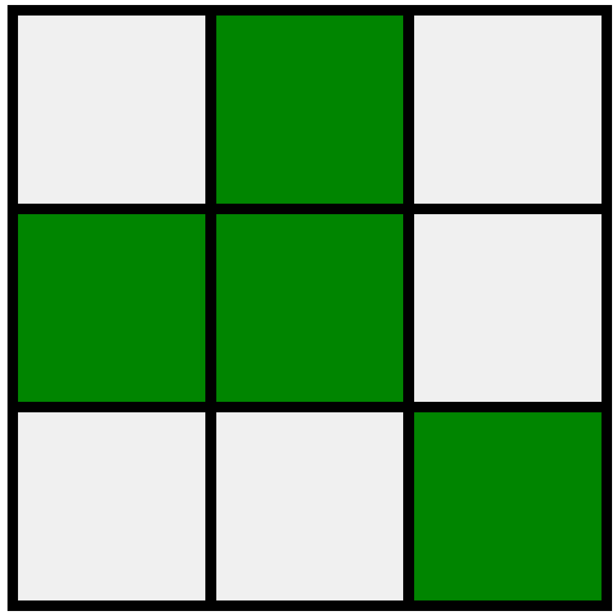
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



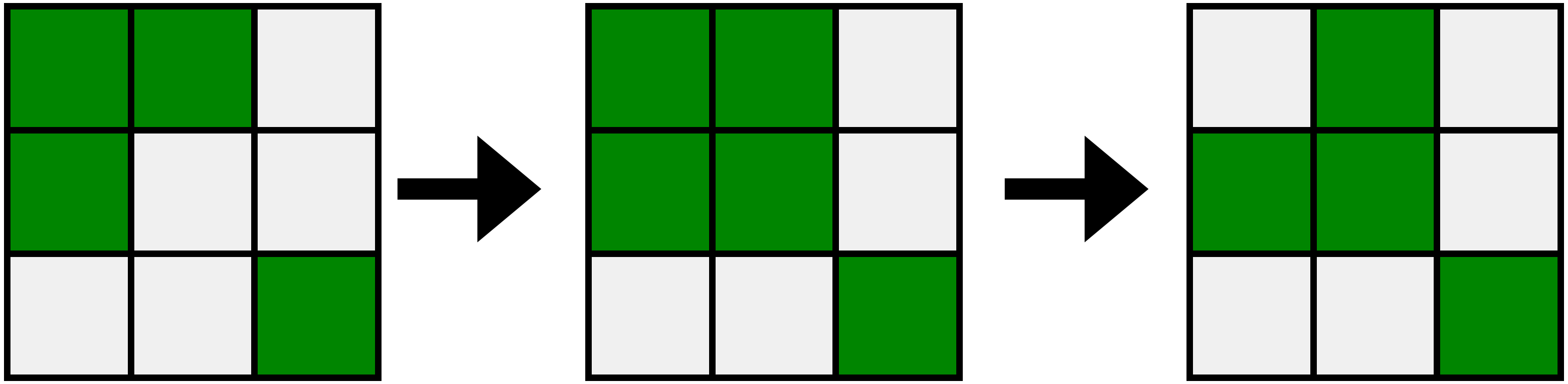
**22 < 26**

Total cost = **22**



*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan



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*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan

**2) Backward steps**

The iterative improvement illustrated above is unlikely to identify the most effective solution → **It does not allow for backward steps** (i.e., changes that increase the solution cost in the short term but would allow long term improvements)

**MARXAN** overcomes this problem by **including a factor** in the iterative process that **allows changes that increases the solution cost**. MARXAN is more likely to accept these changes at the beginning of the process and is more likely to accept larger backward steps.

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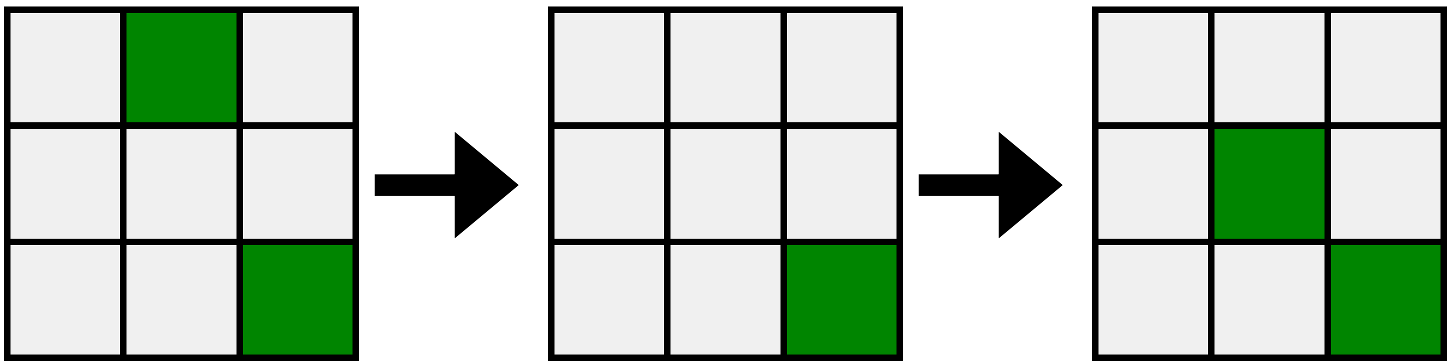
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan

## 2) Backward steps

Total cost = **24** | Total cost = **27** | Total cost = **14**



**Increased cost**

Accepted ✓

**Decreased cost**

Accepted ✓

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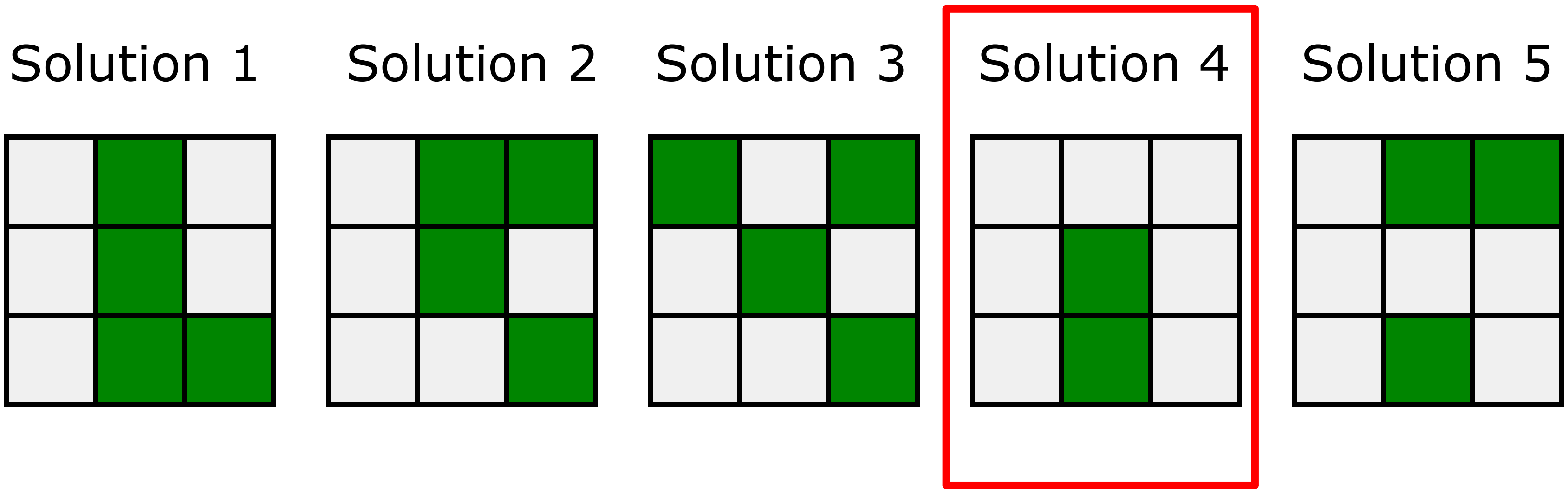
*Source: Bob Smith (DICE)*

# Simulated Annealing in Marxan

## 3) Repetition = Solutions

Repeating the process produces a number of different solutions. The five below were the product of five different runs and all of them meet the targets, although have different cost values.




MARXAN then identifies **the best solution** of the five, based on the lowest score

*Source: Bob Smith (DICE)*

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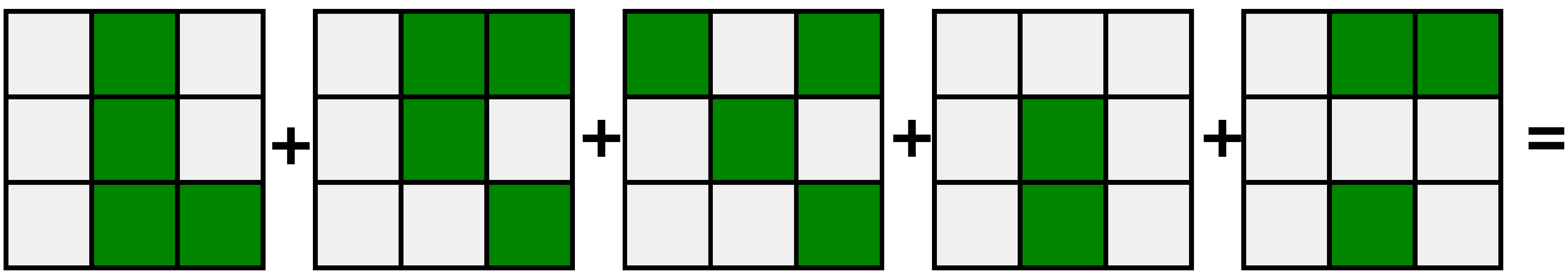
# Simulated Annealing in Marxan

## 3) Repetition = Solutions

The results from the different solutions can also be combined to produce a sum solution score or selection frequency.




| | | |
|---|---|---|
| 1 | 3 | 3 |
| 0 | 4 | 0 |
| 0 | 3 | 3 |

The numbers represent the number of times the PU was selected

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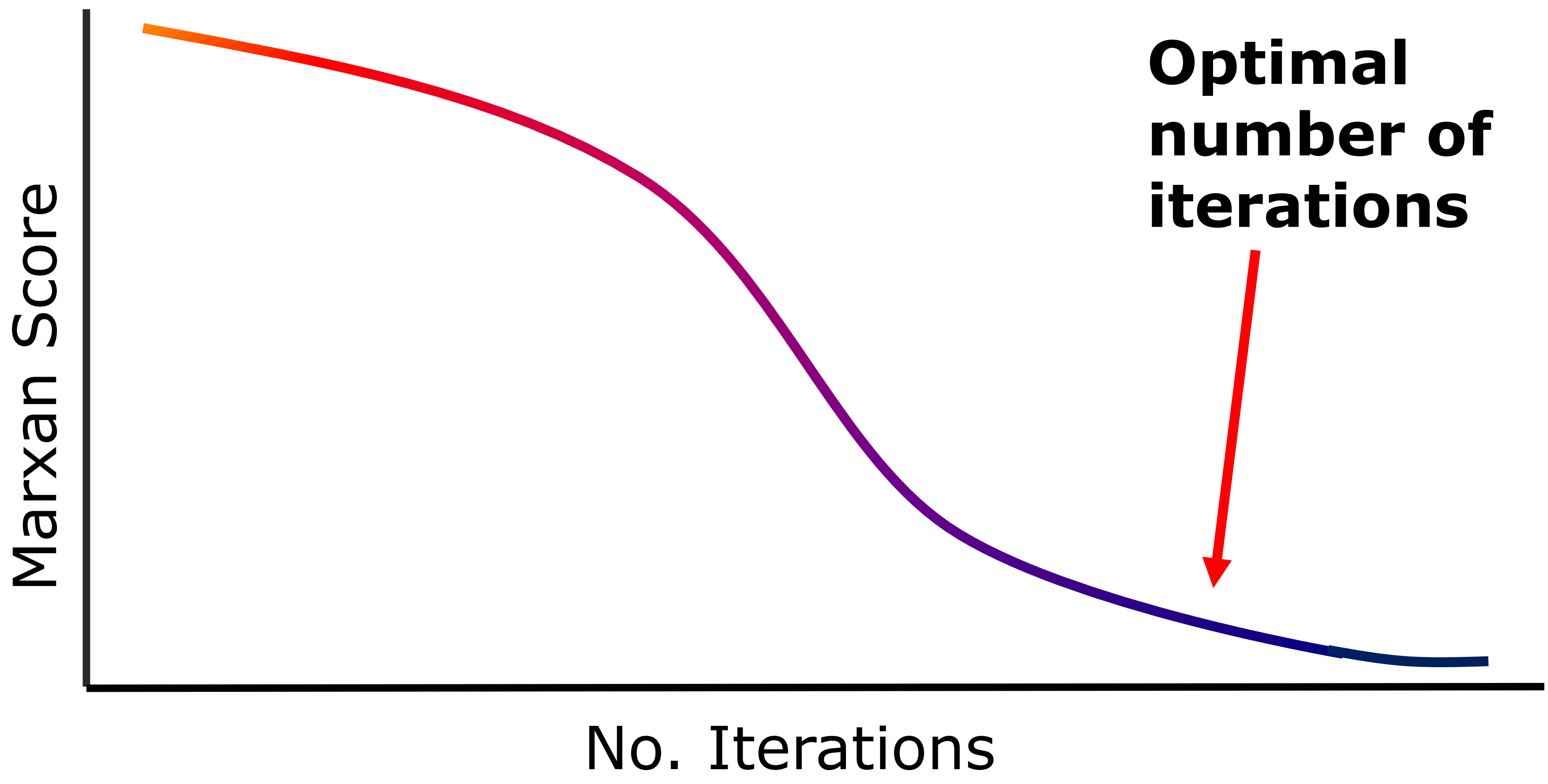
*Source: Bob Smith (DICE)*

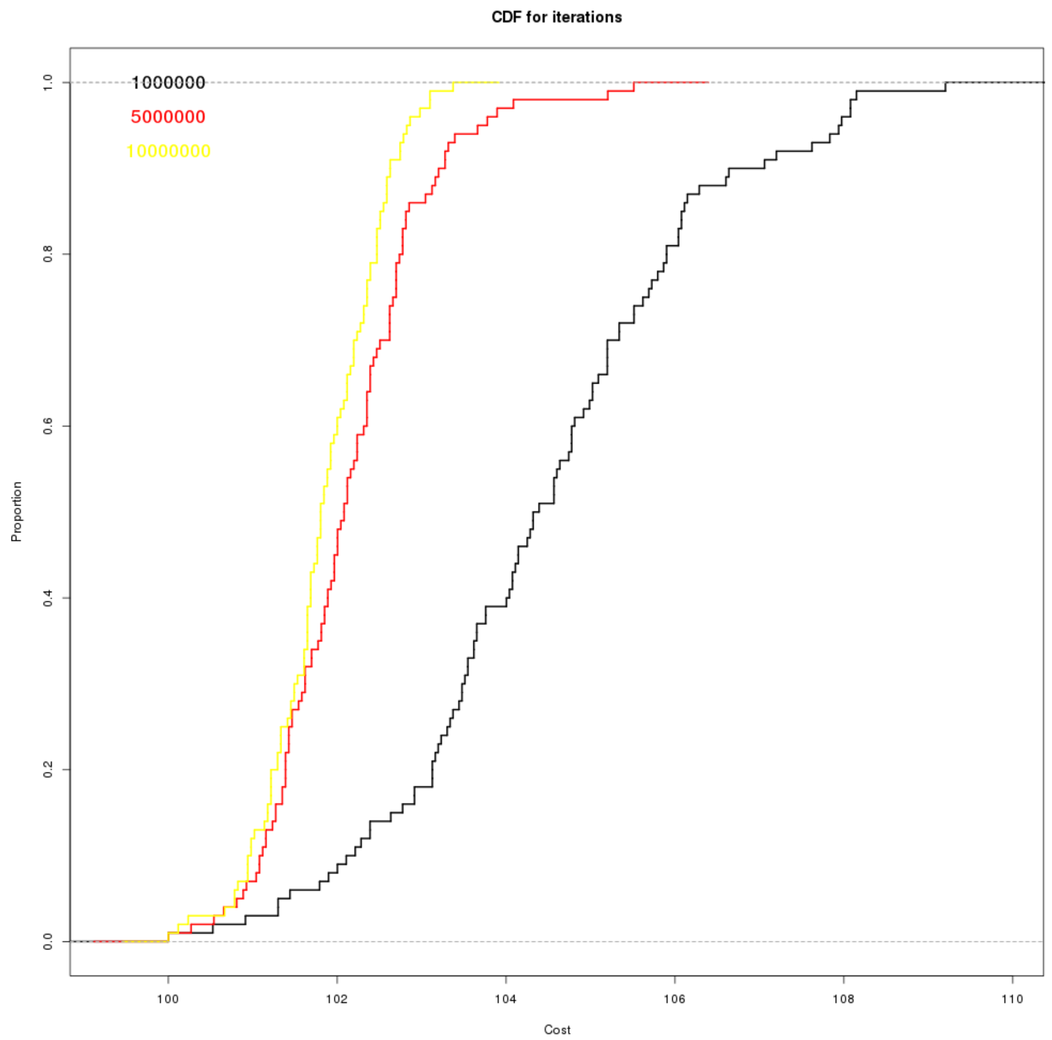
# Simulated Annealing

## How many iterations are necessary?



# Assessing Number of Iterations

**To determine optimal number plot proportion of solutions near optimal cost with a cumulative distribution function. The value furthest left is optimal.**



# Simulated annealing demo in ZC