Design of an Optimal Weather Radar Network for Ireland

Project Supervisor: John Donohue

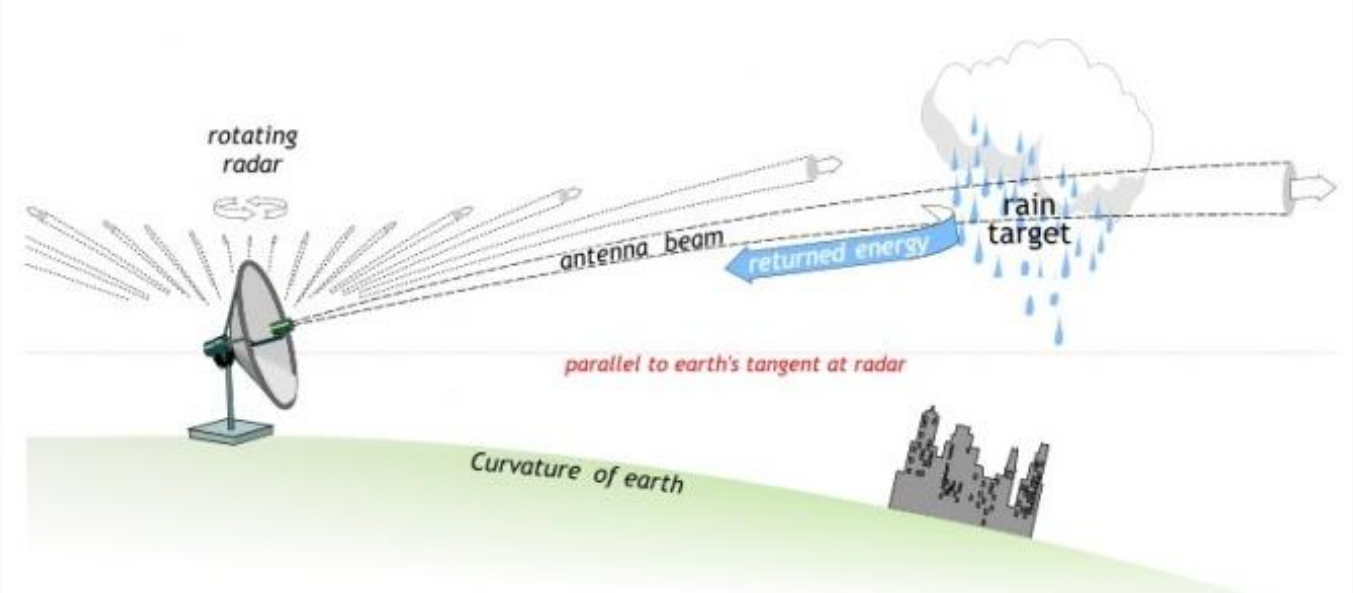
James Allen, Philip Cloherty, John Cormican, Padraic Flood, Tomokatsu Onaga, Brian Regan, David Smyth, Szymon Urbas

June 9, 2017

4th Annual Stokes Modelling Workshop 2017

Problem Introduction

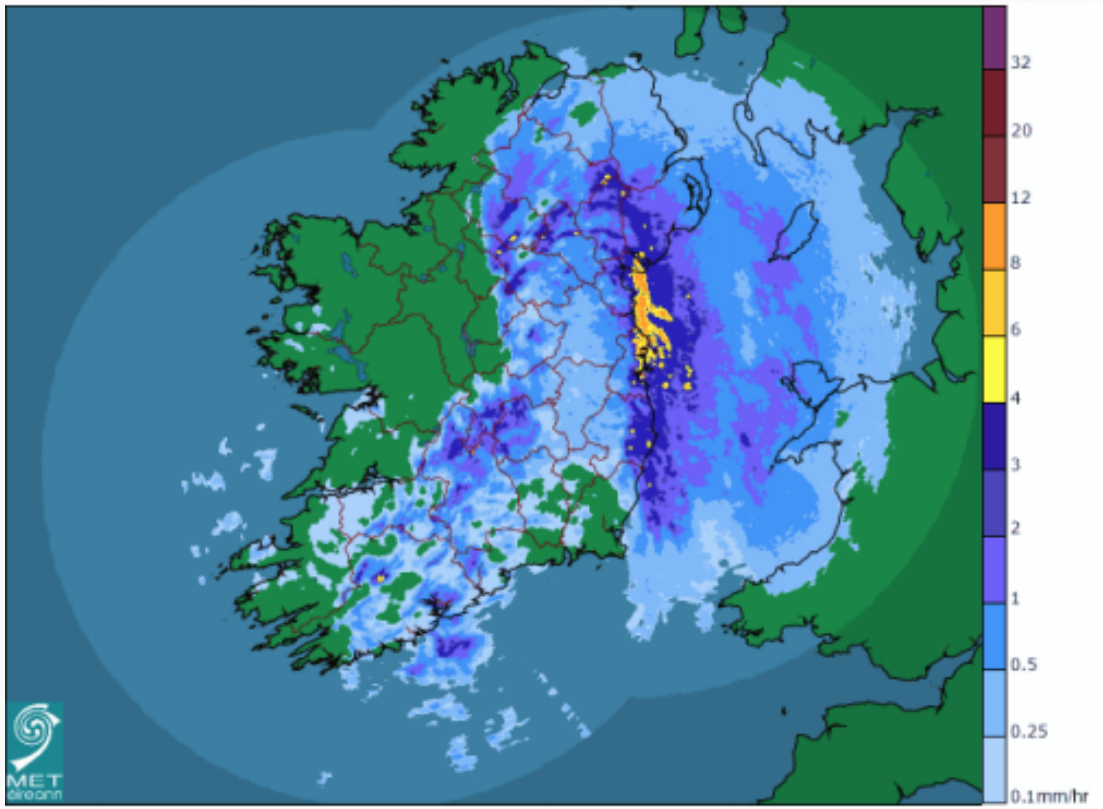
Met Eireann use Radar stations to determine cloud position and predict rainfall.



Problem Introduction

Currently, there are two stations at Dublin and Shannon Airports (as illustrated.

Our Goal: To optimize the positioning of these Radar Stations for two or more locations and improve coverage.



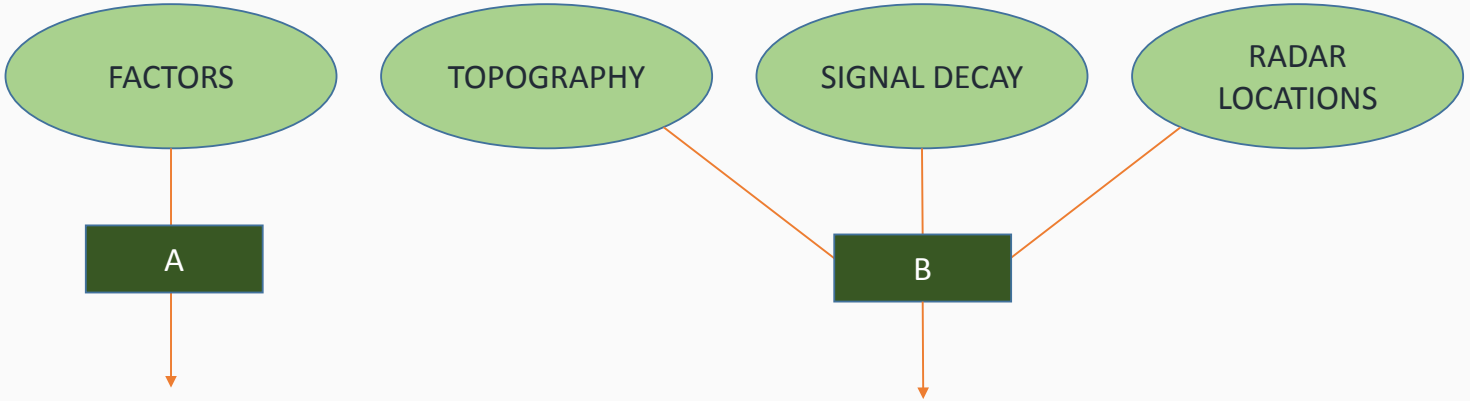
Assumptions

All assumptions, scope exclusions and decisions were made in consultation with Colm Clancy of Met Eireann.

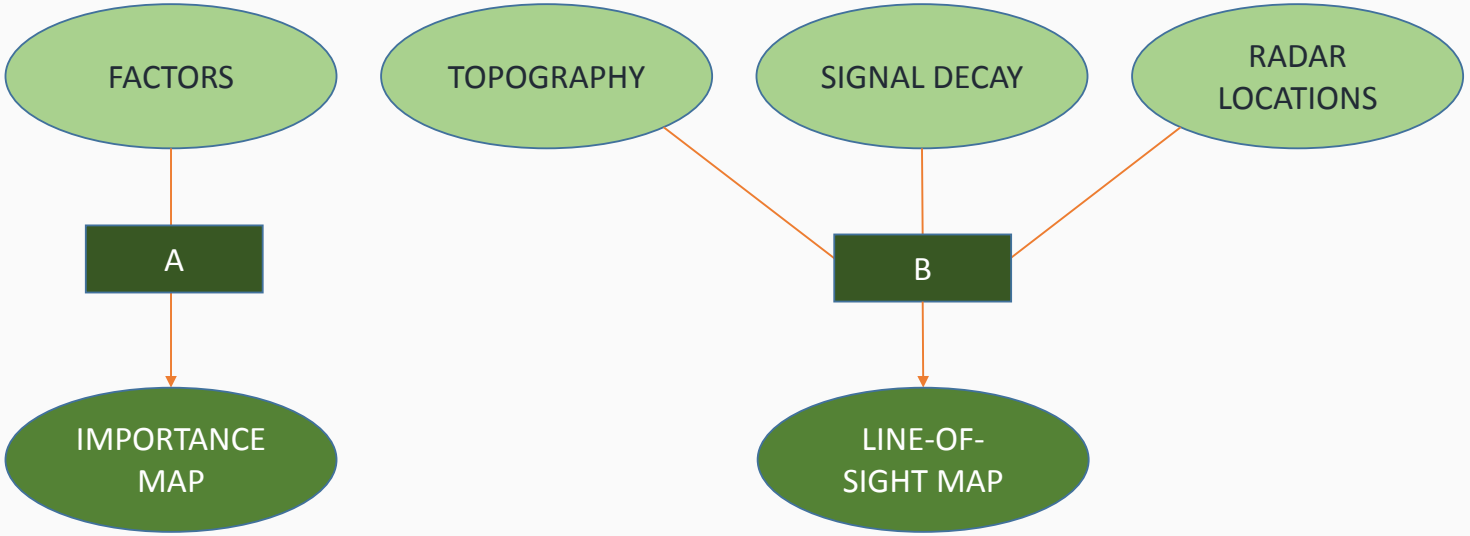
1. Constant Temperature.
2. Time Invariance (No Seasons).
3. Precipitation at sea is not considered.
4. Northern Ireland: Assumed population of zero and no airports.

Framework

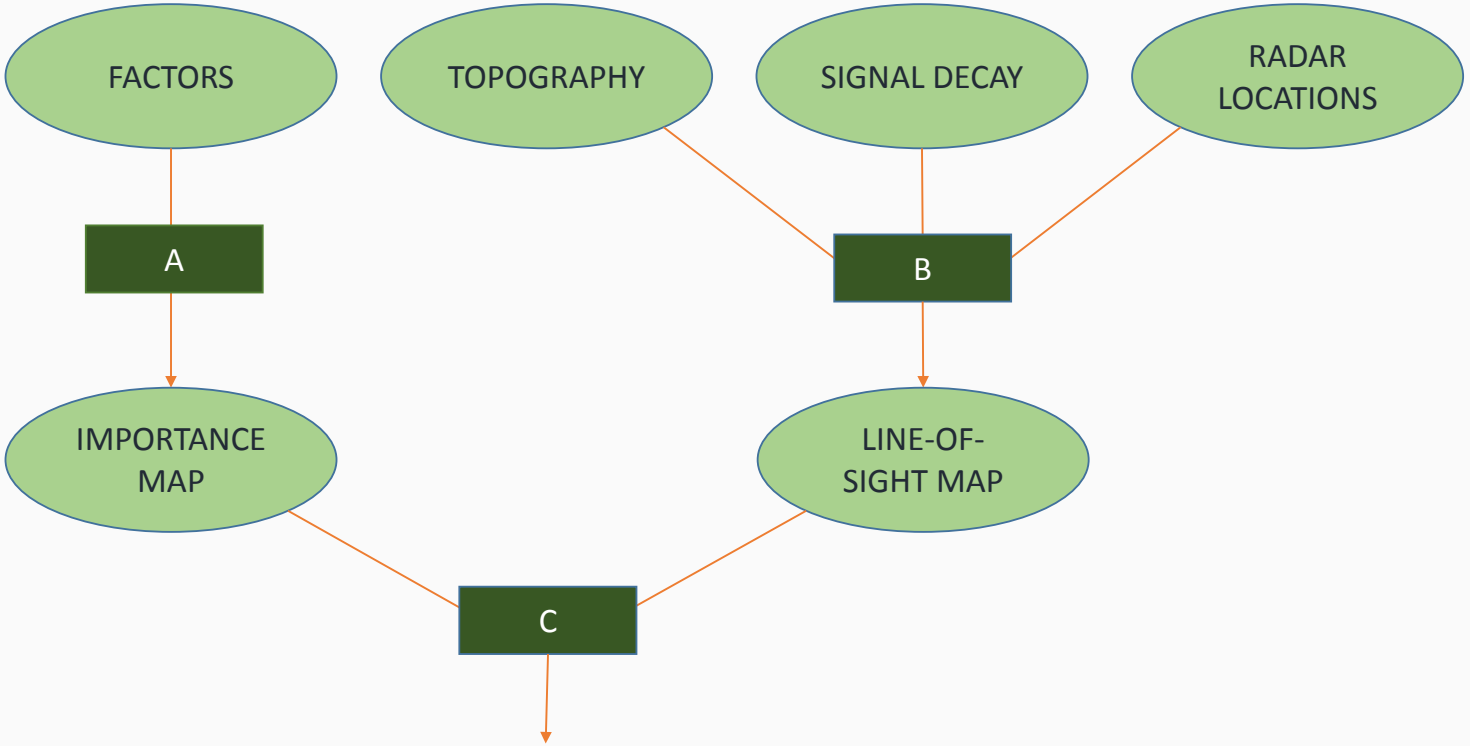
Framework



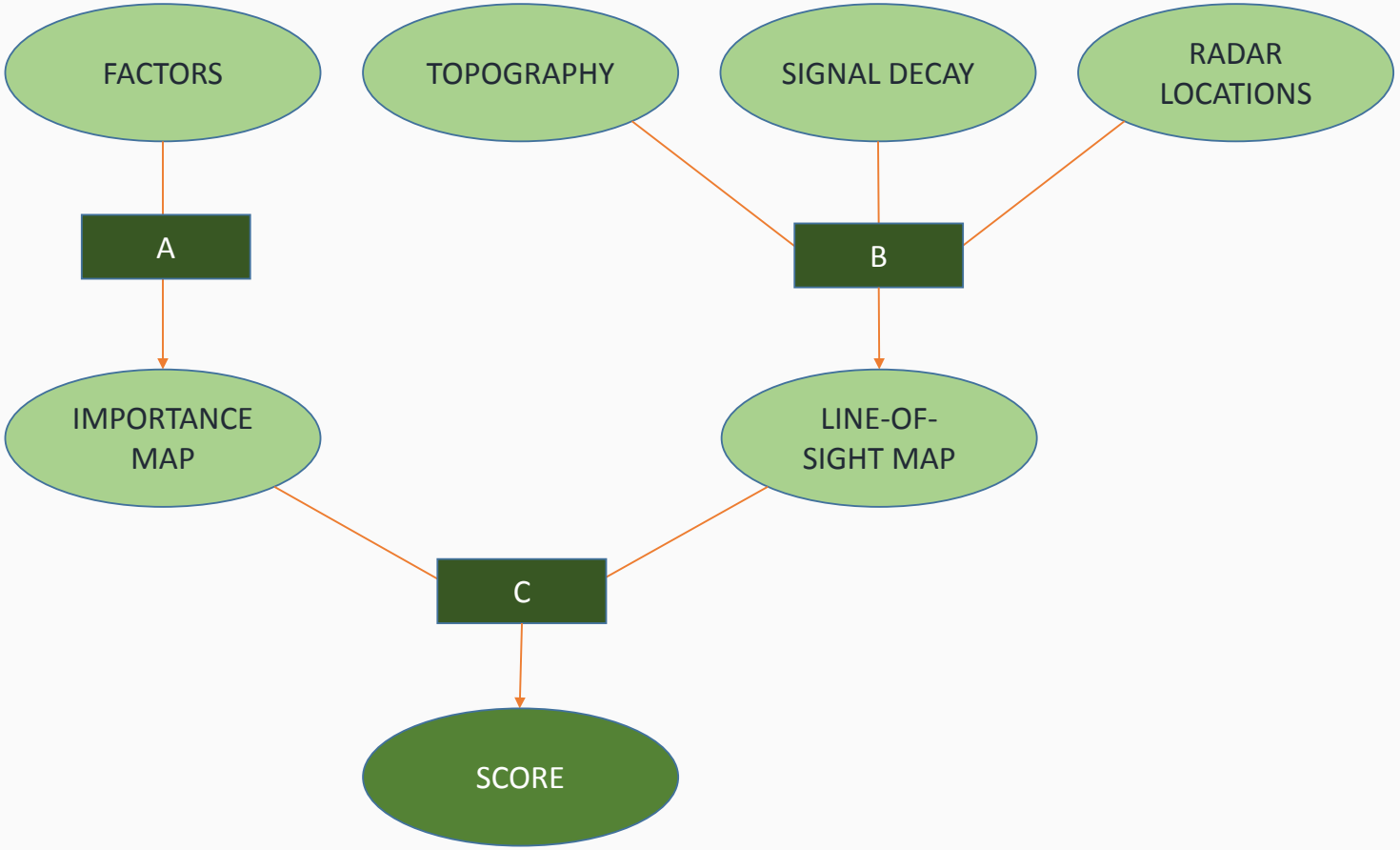
Framework


FACTORS
TOPOGRAPHY
SIGNAL DECAY
RADAR LOCATIONS
A
B
IMPORTANCE MAP
LINE-OF-SIGHT MAP

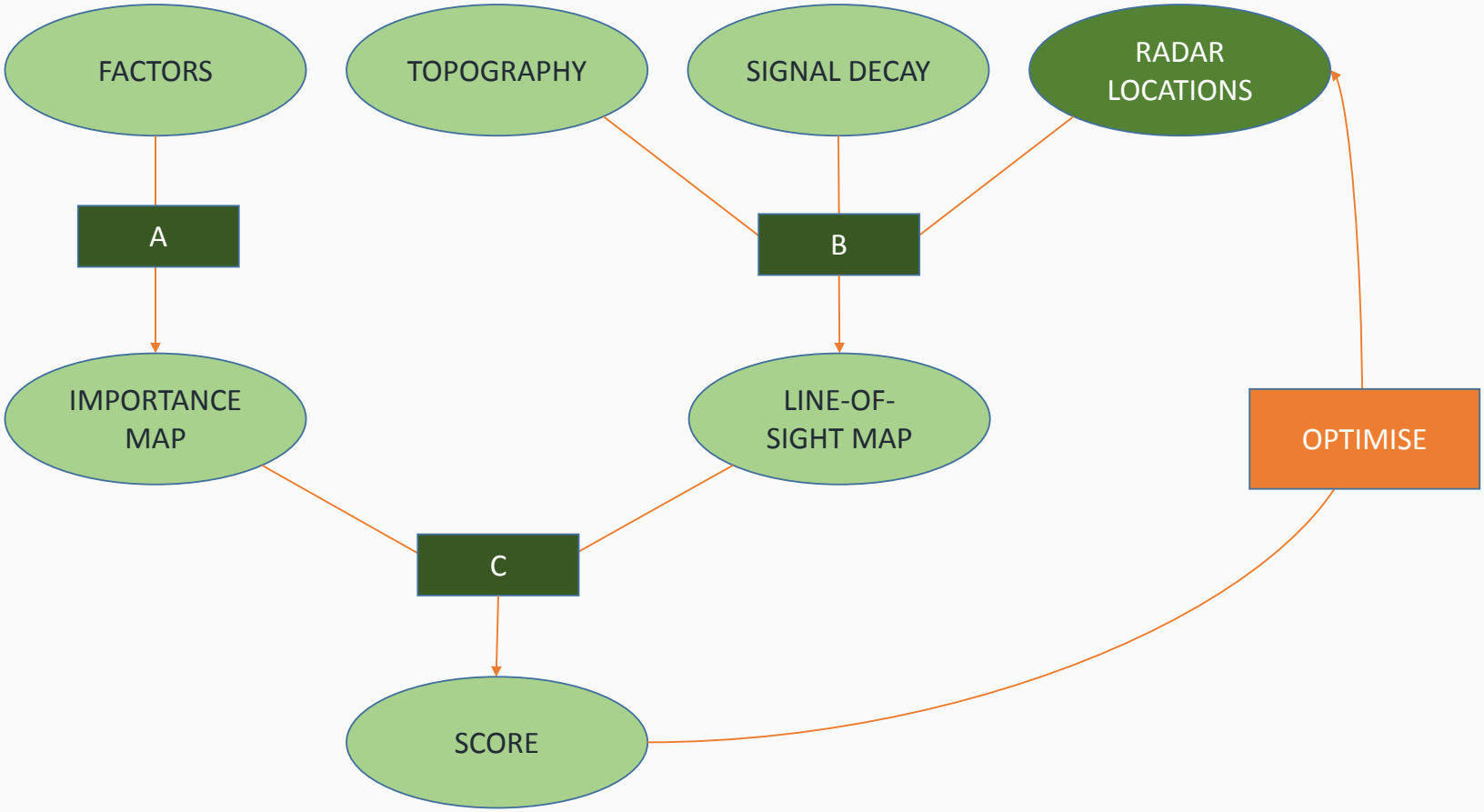
Framework


FACTORS
TOPOGRAPHY
SIGNAL DECAY
RADAR LOCATIONS
A
B
IMPORTANCE MAP
LINE-OF-SIGHT MAP
C

Framework

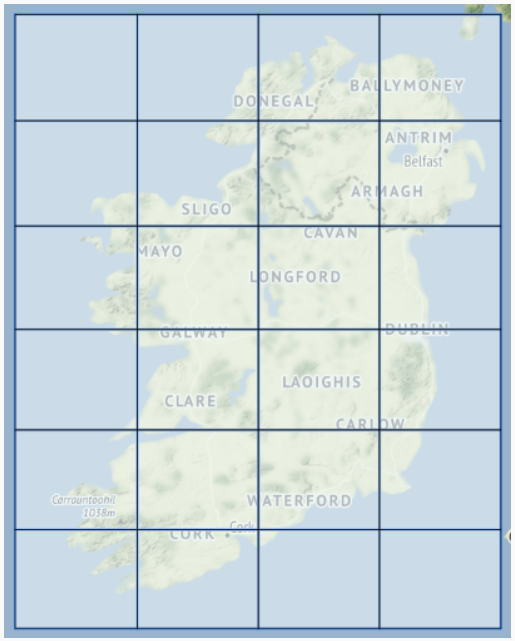

FACTORS
TOPOGRAPHY
SIGNAL DECAY
RADAR LOCATIONS
A
B
IMPORTANCE MAP
LINE-OF-SIGHT MAP
C
SCORE

Framework

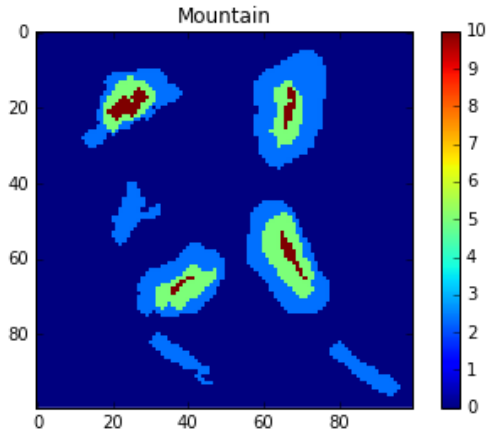

FACTORS
TOPOGRAPHY
SIGNAL DECAY
RADAR LOCATIONS
A
B
IMPORTANCE MAP
LINE-OF-SIGHT MAP
OPTIMISE
C
SCORE

Prioritisation of areas to be covered

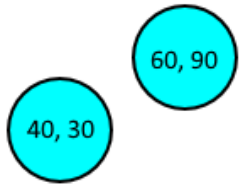
- Areas prioritized werebased on three factors:
  1. Areas with an Airport
  2. Areas with High Population Density
  3. Areas with High Rainfall
- Map of Ireland was divided into cells.
- Importance of each cell was evaluated.



Designing the Radar

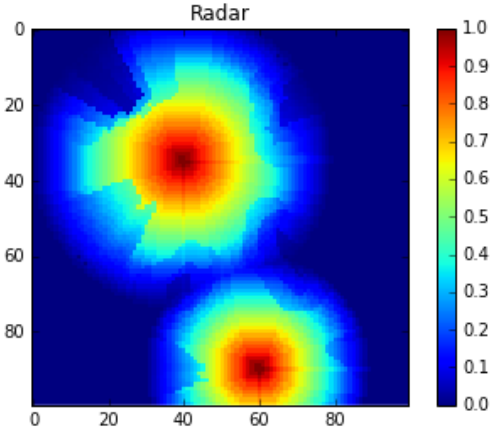


Topological Map

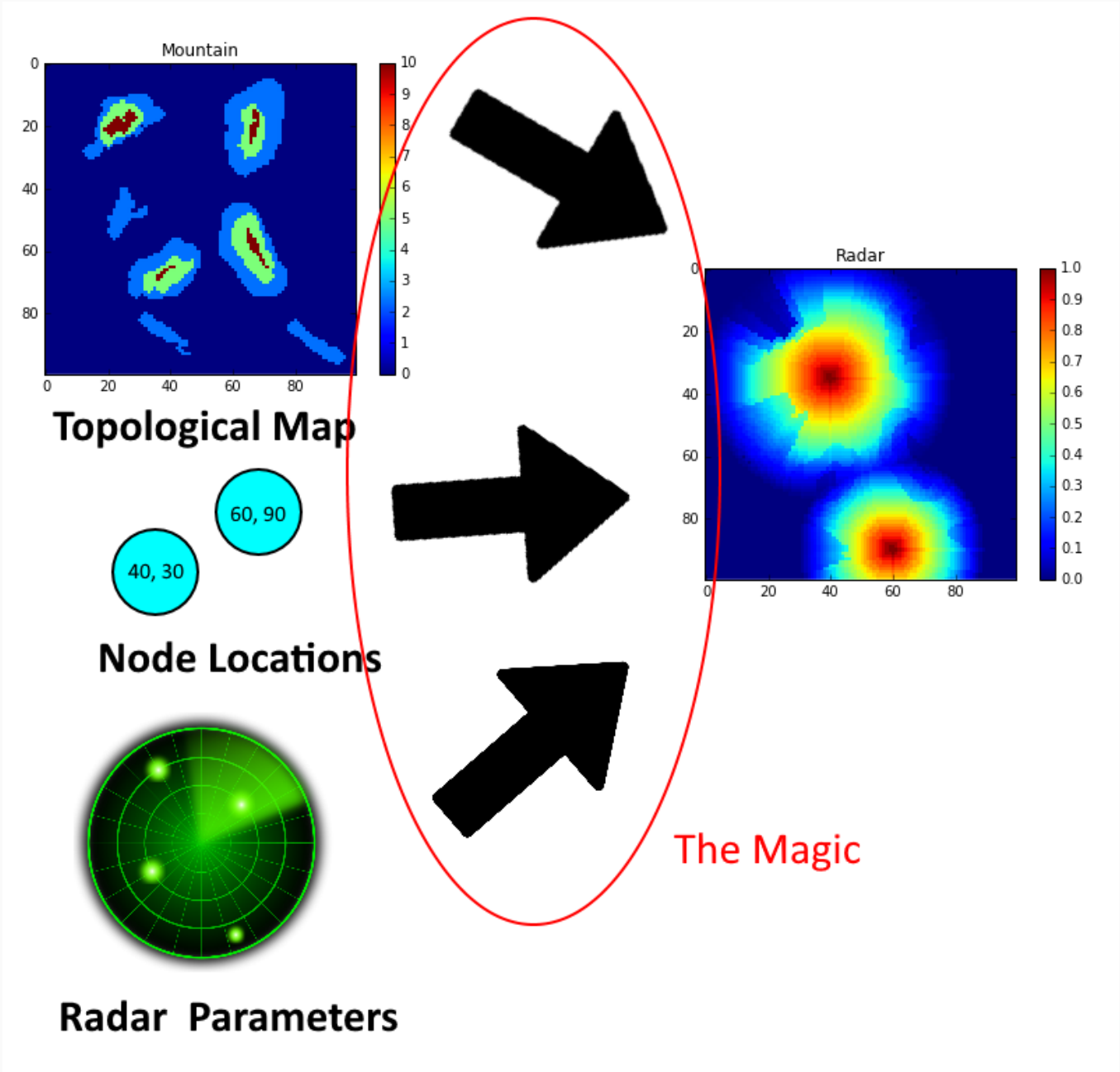


Node Locations

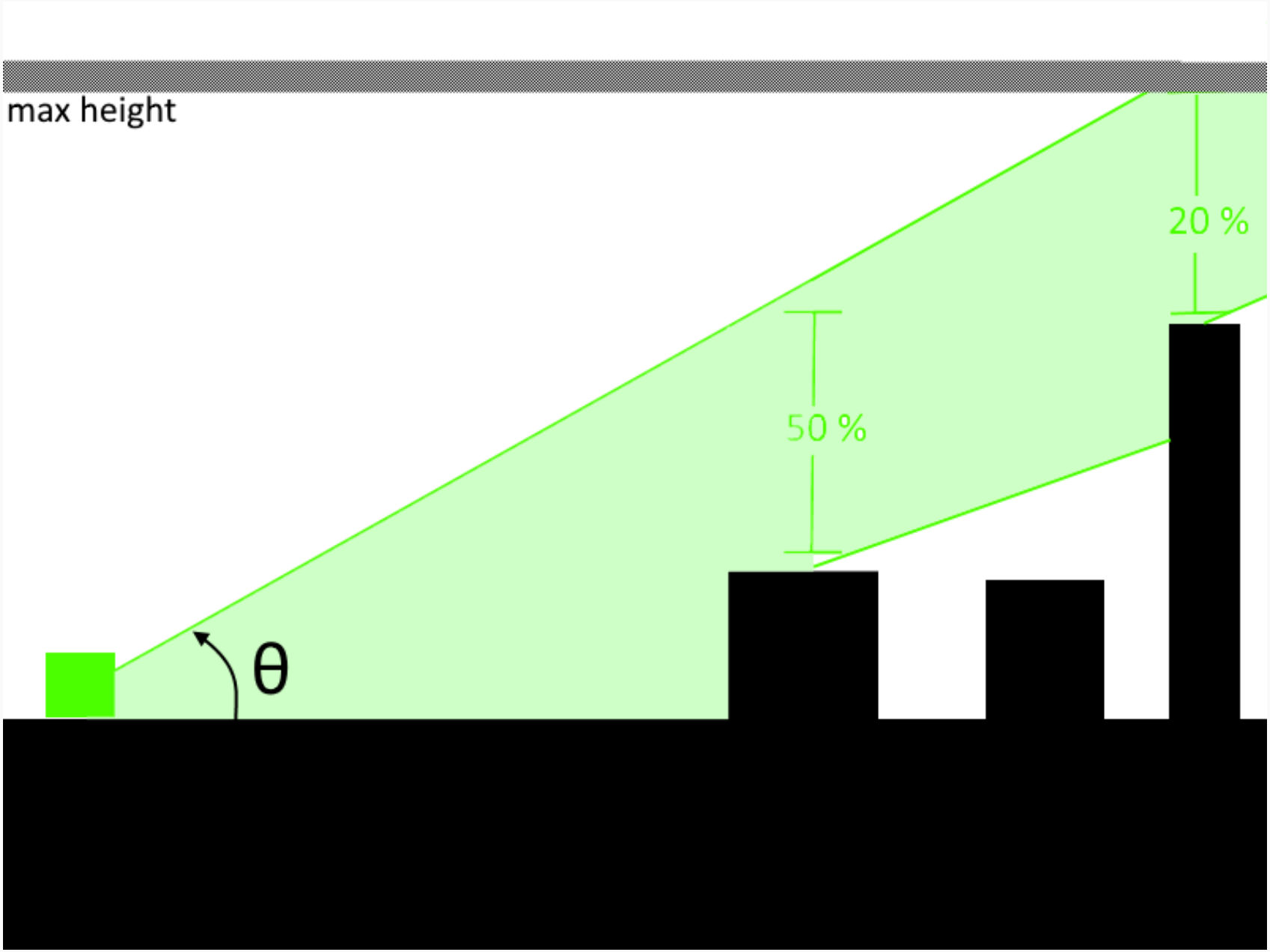
Radar Parameters



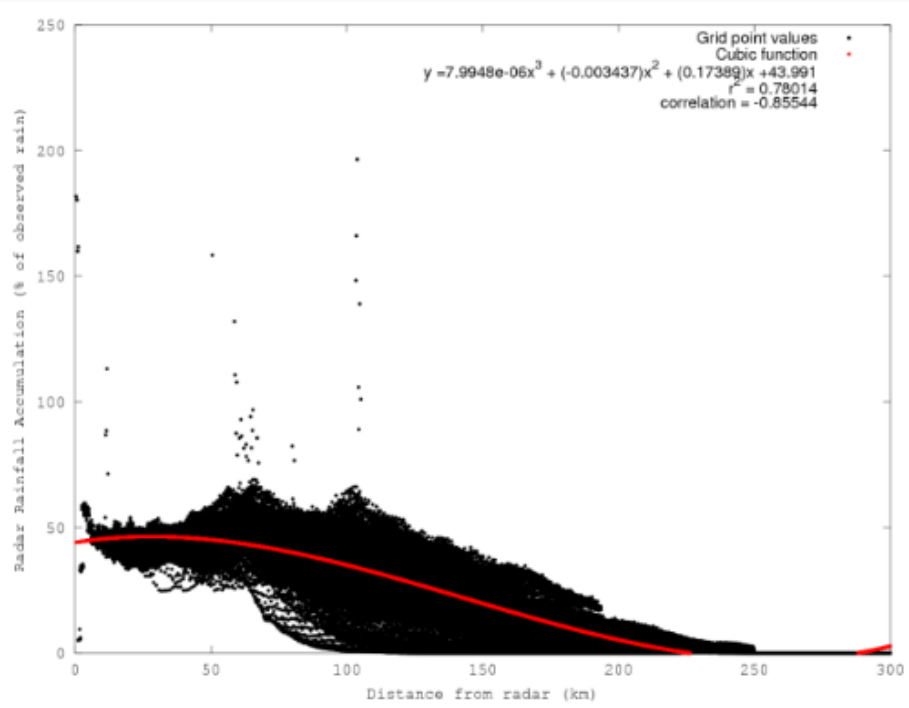
Designing the Radar

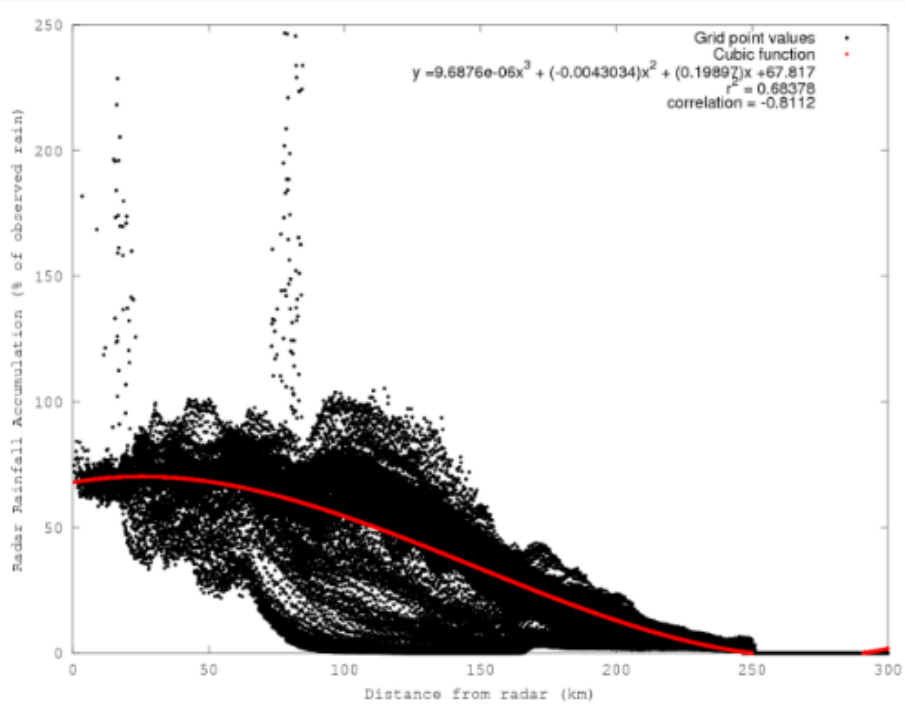


Line of Sight

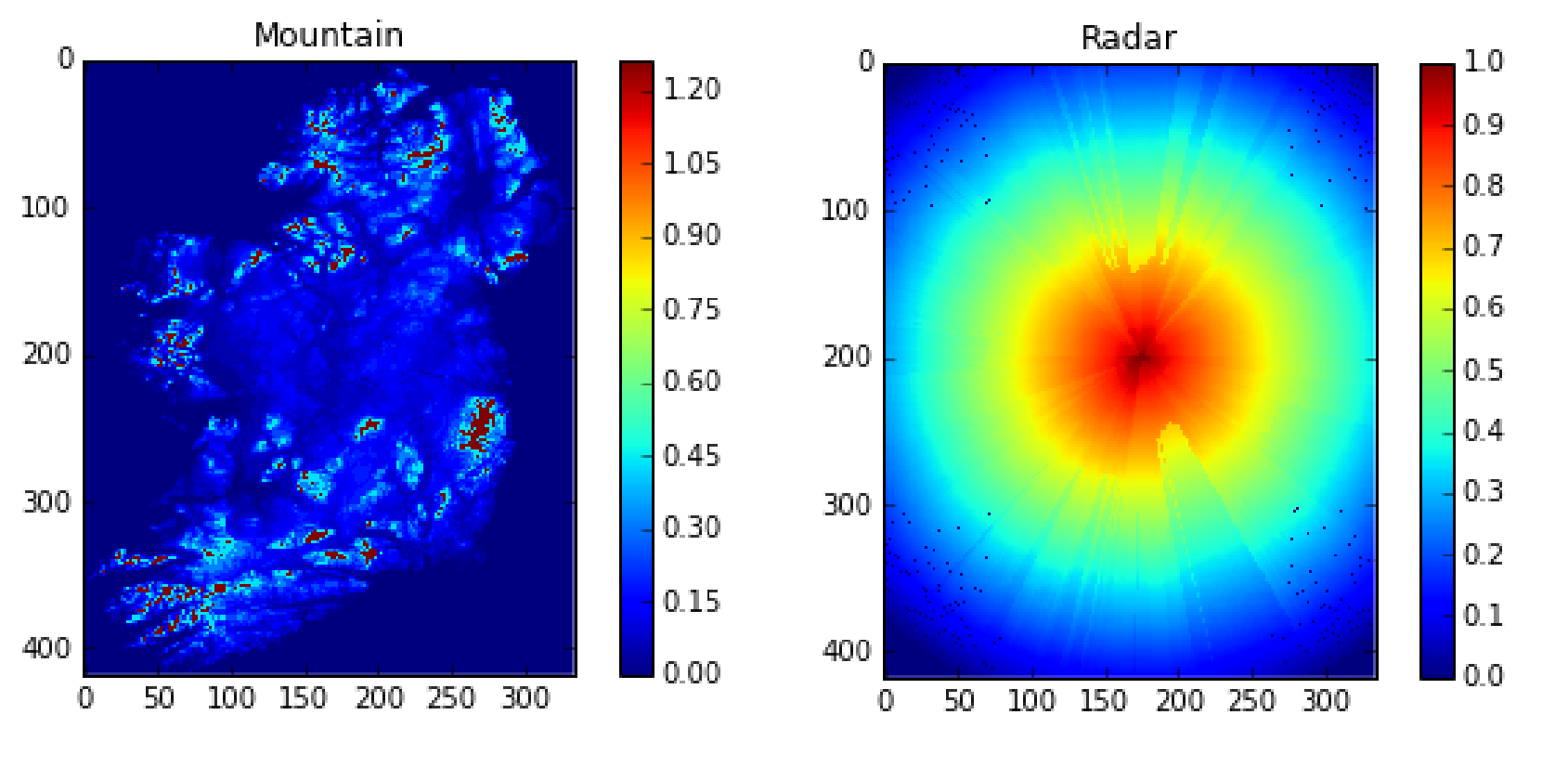


Radar Signal Decay





Designing the Radar



Objective Function and Scoring of Radar Formations

- Possible radar formations were combined with the Quality Map to give a score for how efficient the configuration was.
- This score was input into the optimisation process until the ideal location was identified.

Searching for optimal placement

A toy problem

$$R(x, x_c) = a^2 - (x - x_c)^2 \tag{1}$$

A toy problem

$$R(x, x_c) = a^2 - (x - x_c)^2 \tag{1}$$

To find the total score multiply the importance function and the radar...

$$S(x_c) = \int_0^L Q(x)R(x, x_c)dx \tag{2}$$

$$= \int_{Q_1} Q_1(a^2 - (x - x_c)^2)dx + ... + \int_{Q_n} Q_n(a^2 - (x - x_c)^2)dx \tag{3}$$

A toy problem

$$R(x, x_c) = a^2 - (x - x_c)^2 \tag{1}$$

To find the total score multiply the importance function and the radar...

$$S(x_c) = \int_0^L Q(x)R(x, x_c)dx \tag{2}$$

$$= \int_{Q_1} Q_1(a^2 - (x - x_c)^2)dx + ... + \int_{Q_n} Q_n(a^2 - (x - x_c)^2)dx \tag{3}$$

$$\frac{\partial S}{\partial x_c} = 0 \tag{4}$$

A toy problem

$$R(x, x_c) = a^2 - (x - x_c)^2 \tag{1}$$

To find the total score multiply the importance function and the radar...

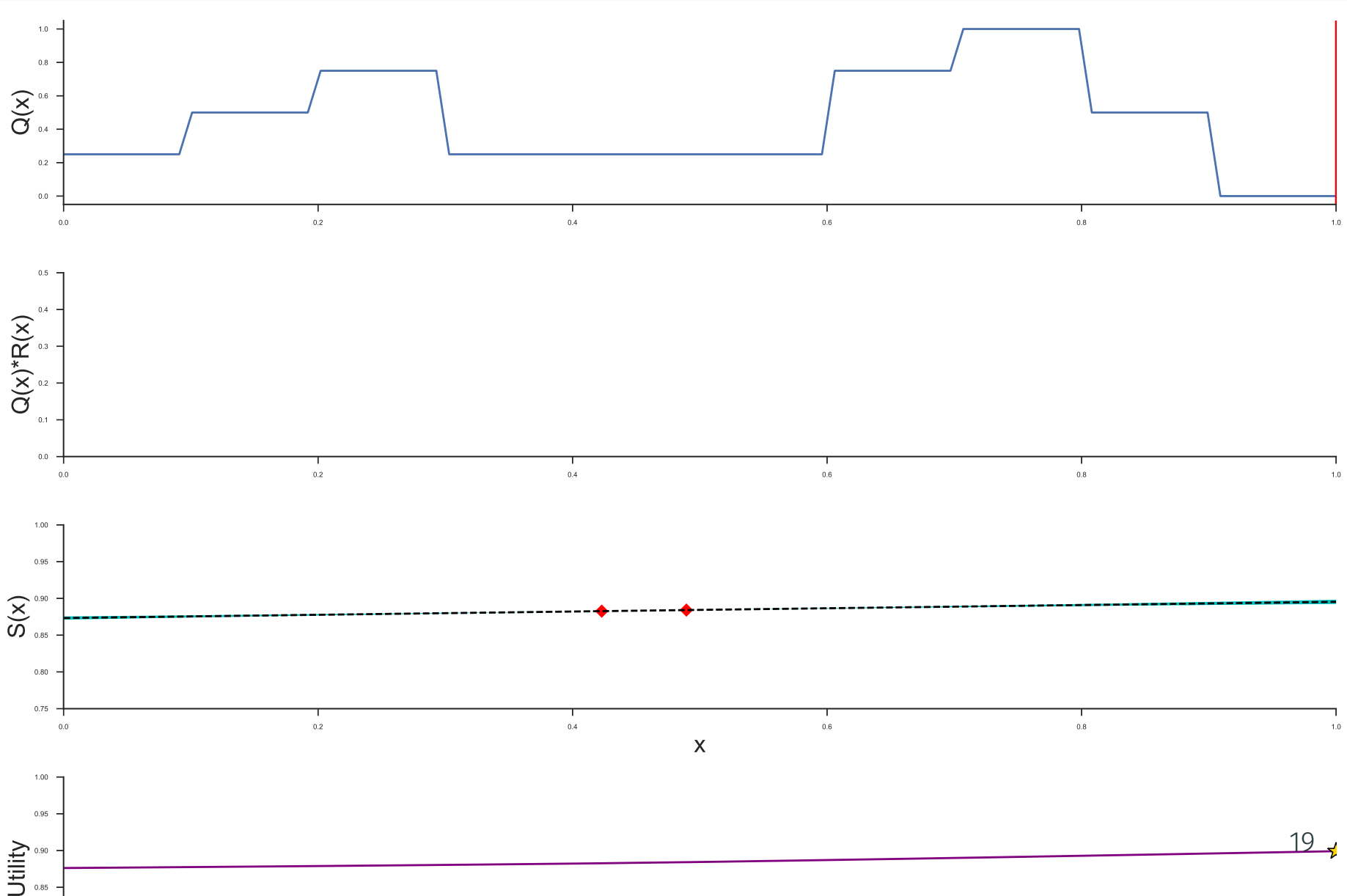
$$S(x_c) = \int_0^L Q(x)R(x, x_c)dx \tag{2}$$

$$= \int_{Q_1} Q_1(a^2 - (x - x_c)^2)dx + ... + \int_{Q_n} Q_n(a^2 - (x - x_c)^2)dx \tag{3}$$

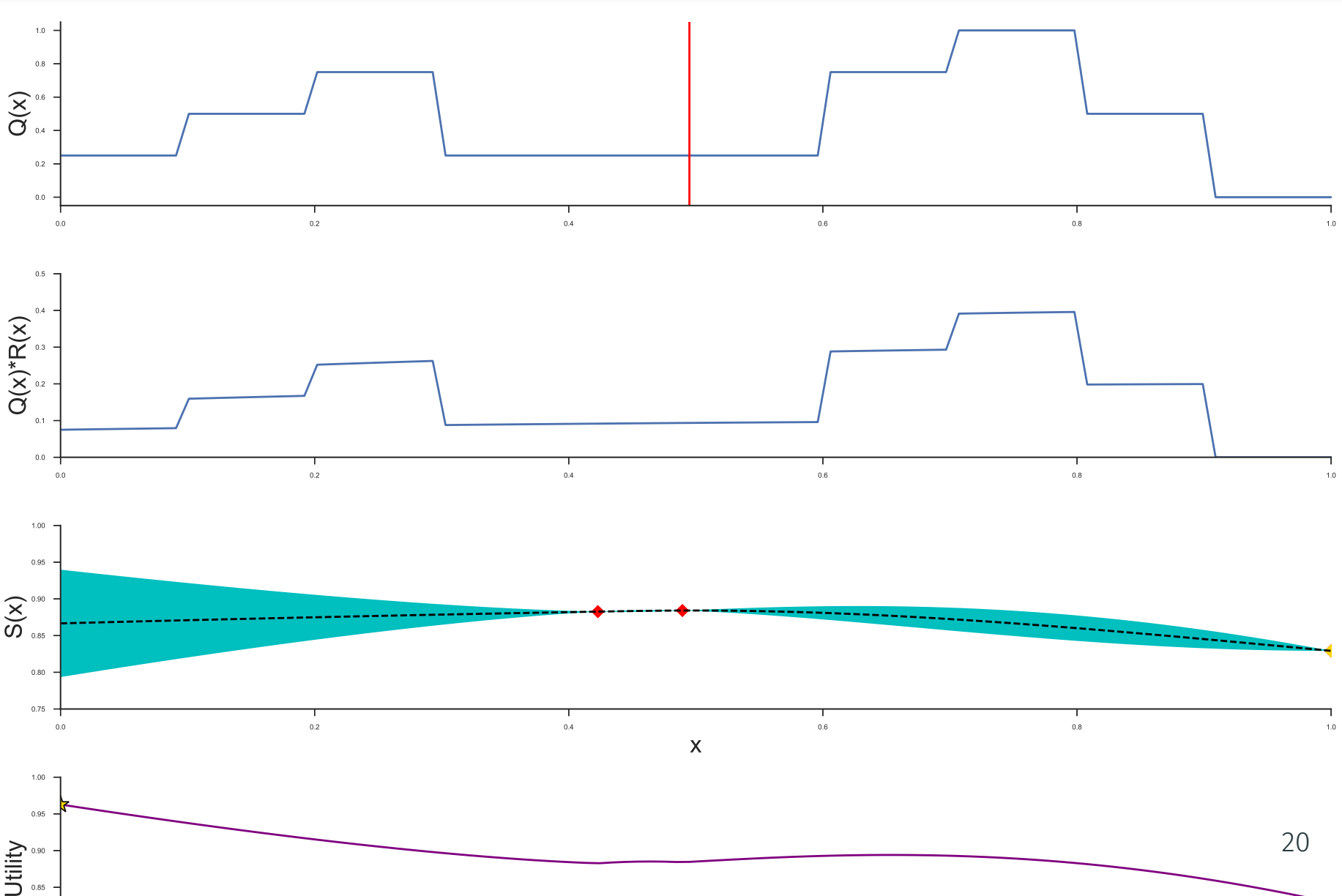
$$\frac{\partial S}{\partial x_c} = 0 \tag{4}$$

$$x_c = 0.5056 \tag{5}$$

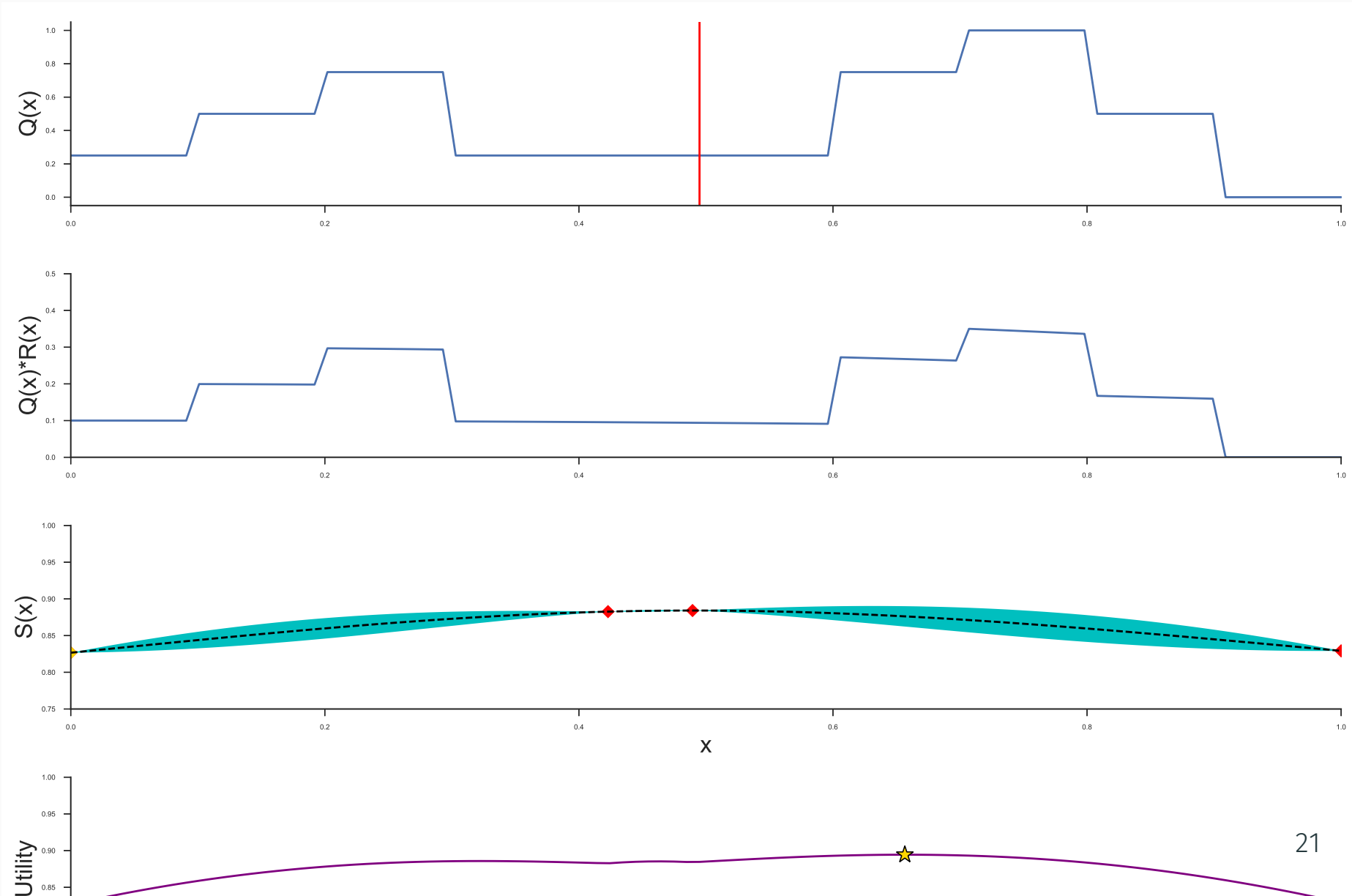
Bayesian optimization



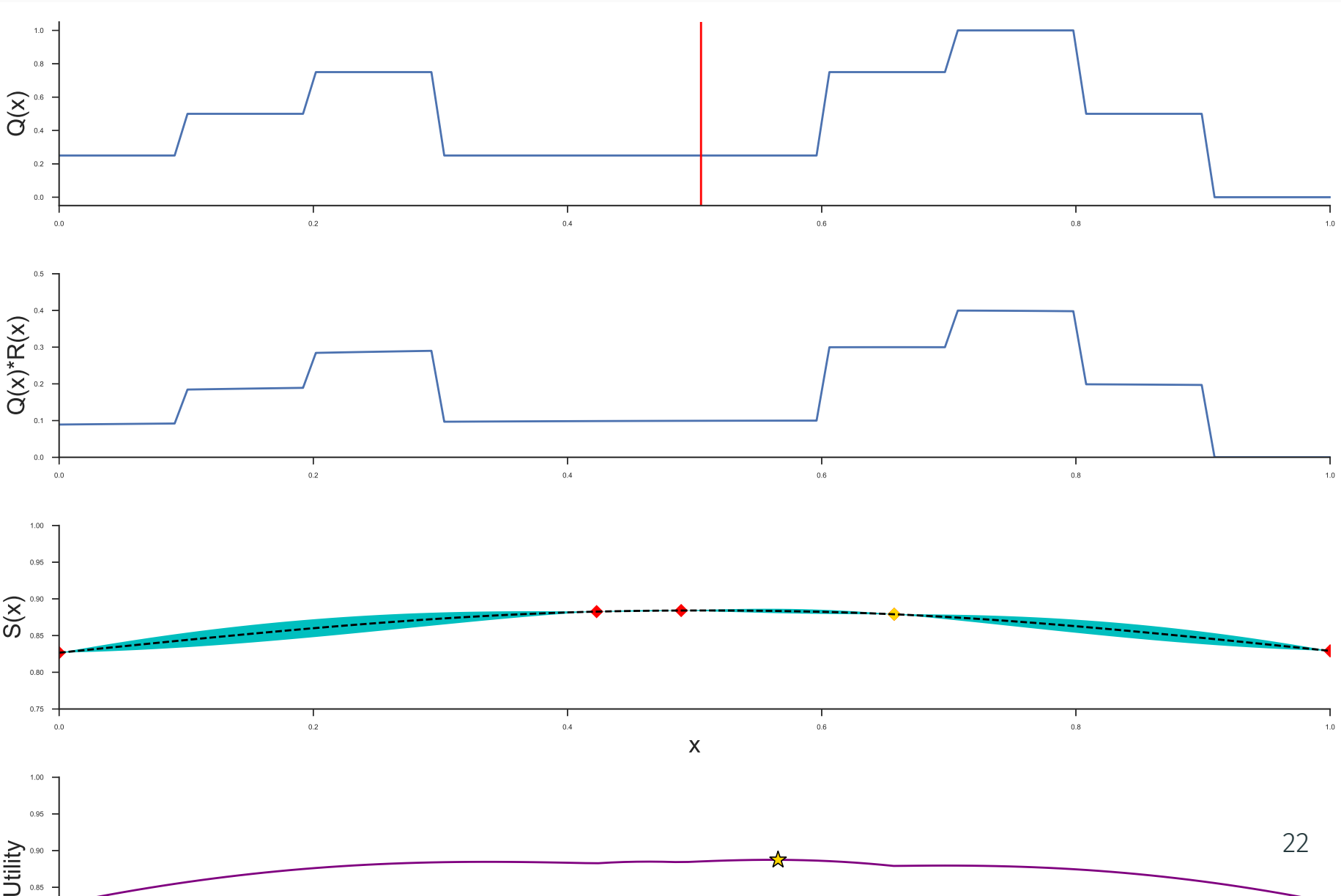
Bayesian optimization



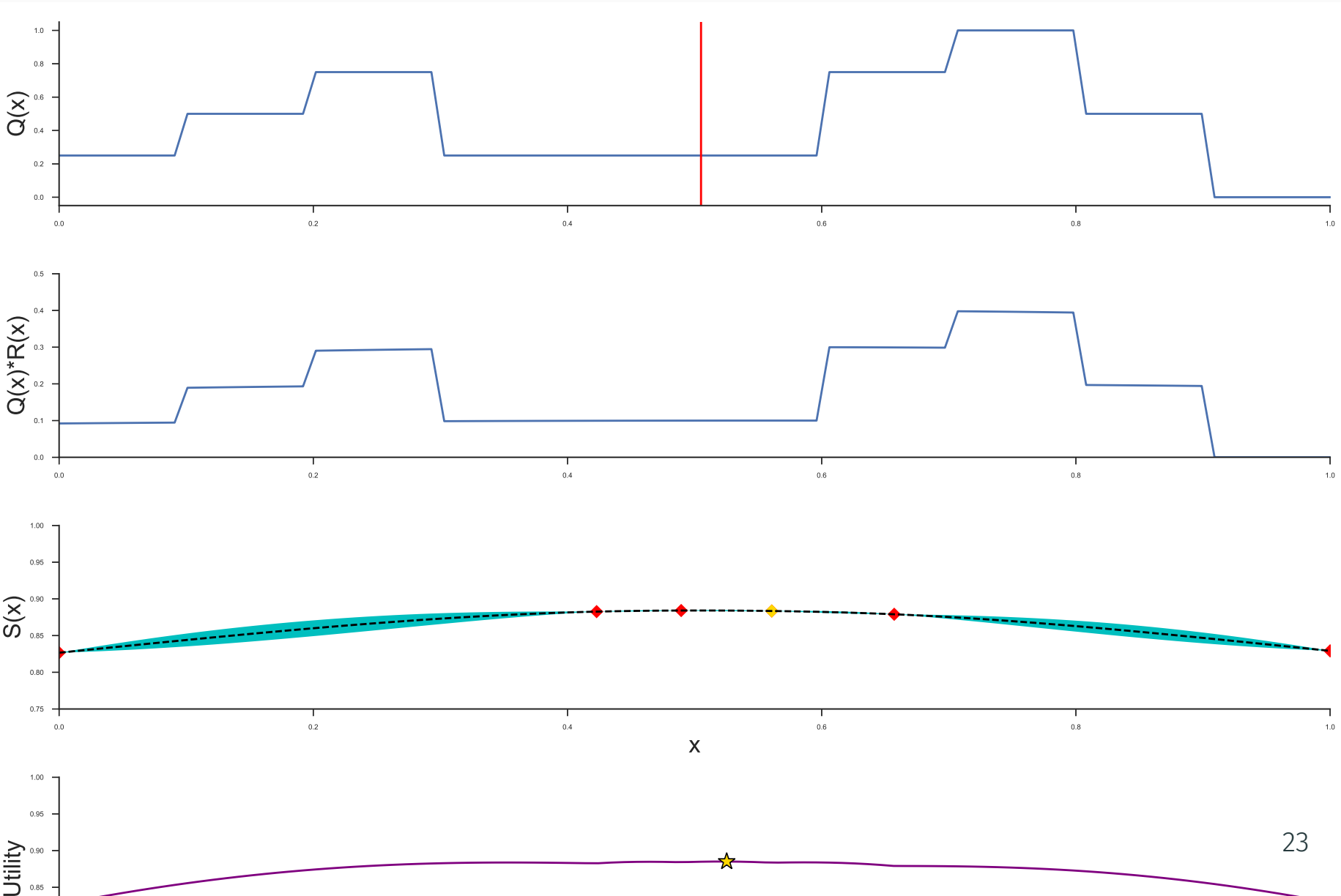
Bayesian optimization



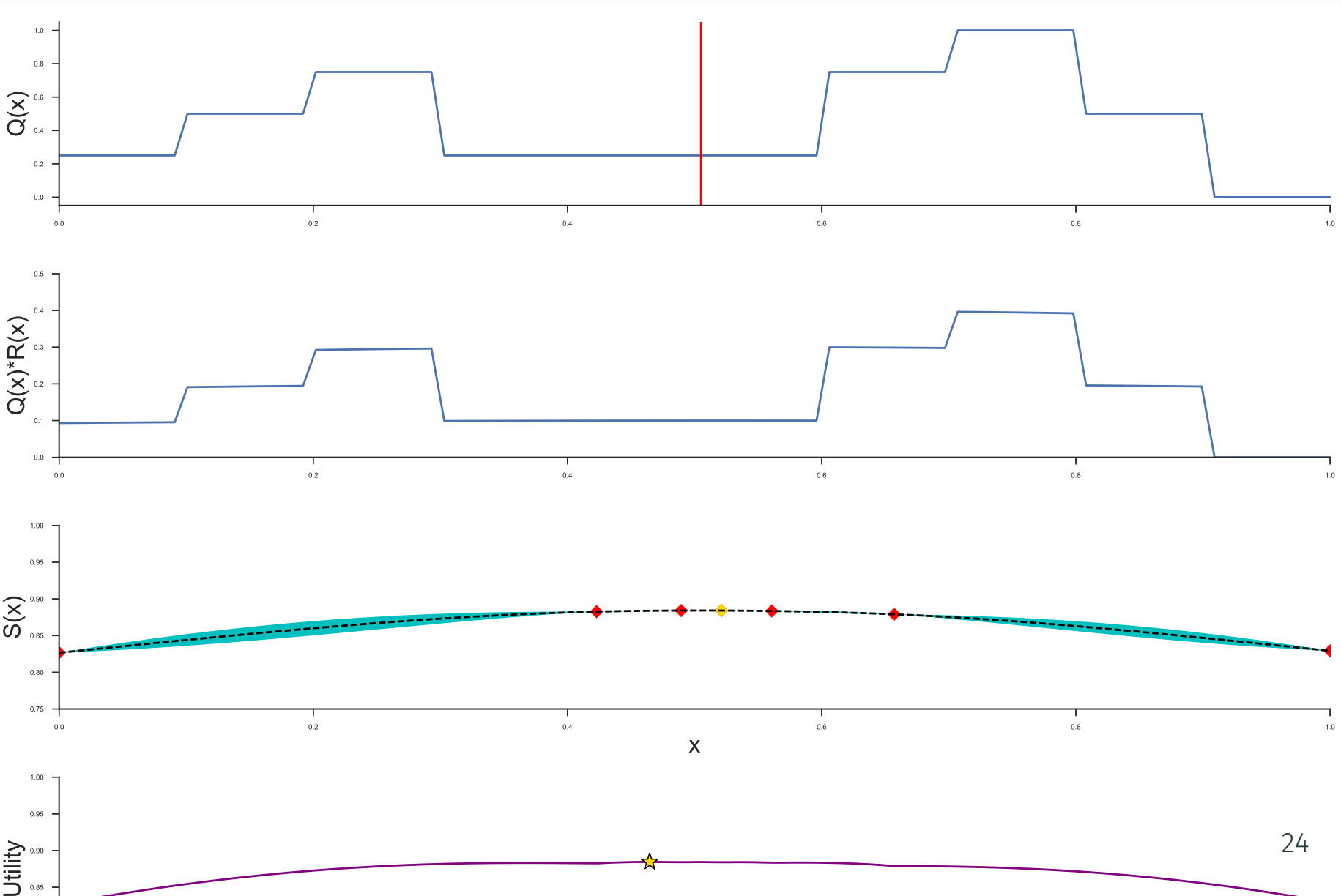
Bayesian optimization



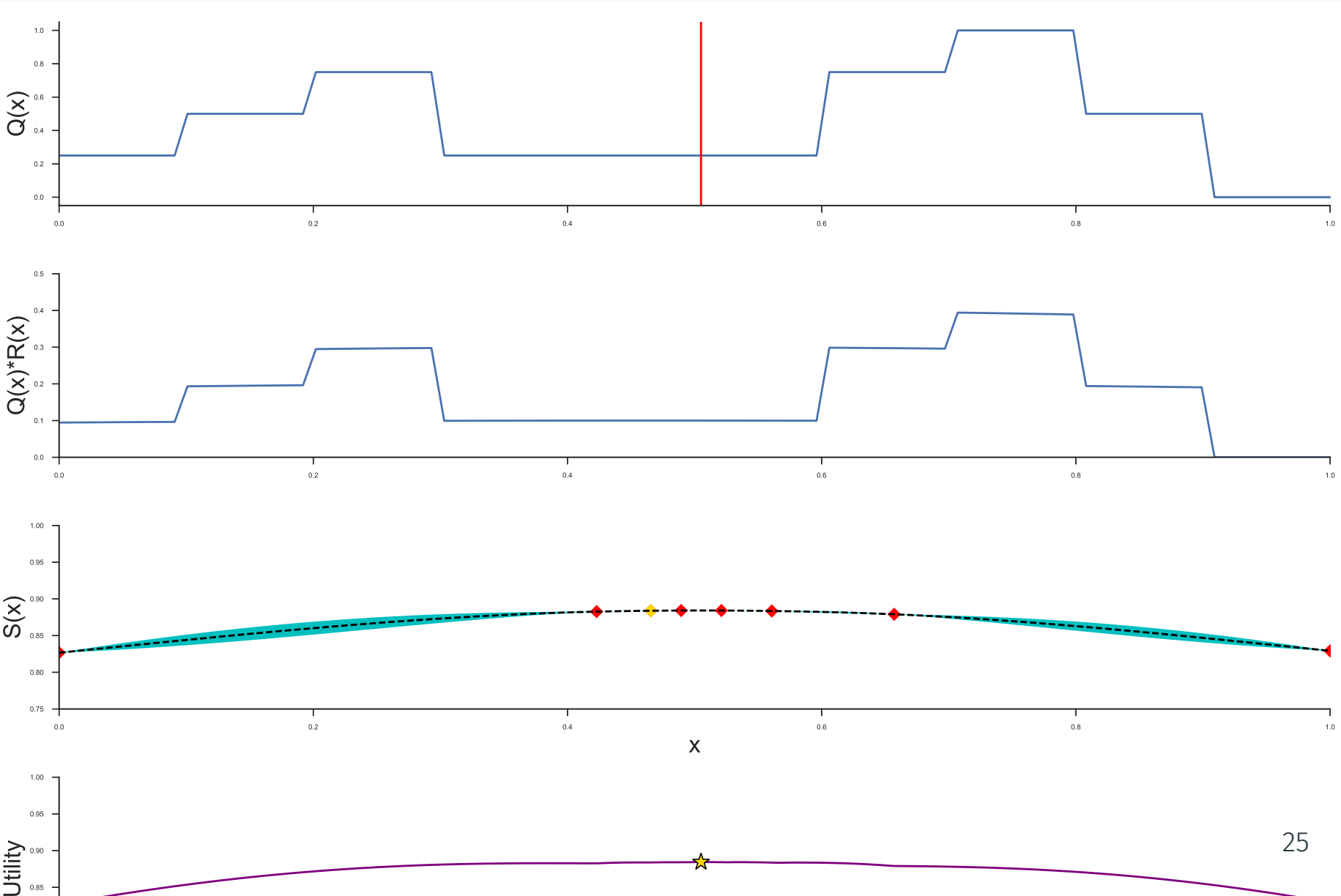
Bayesian optimization



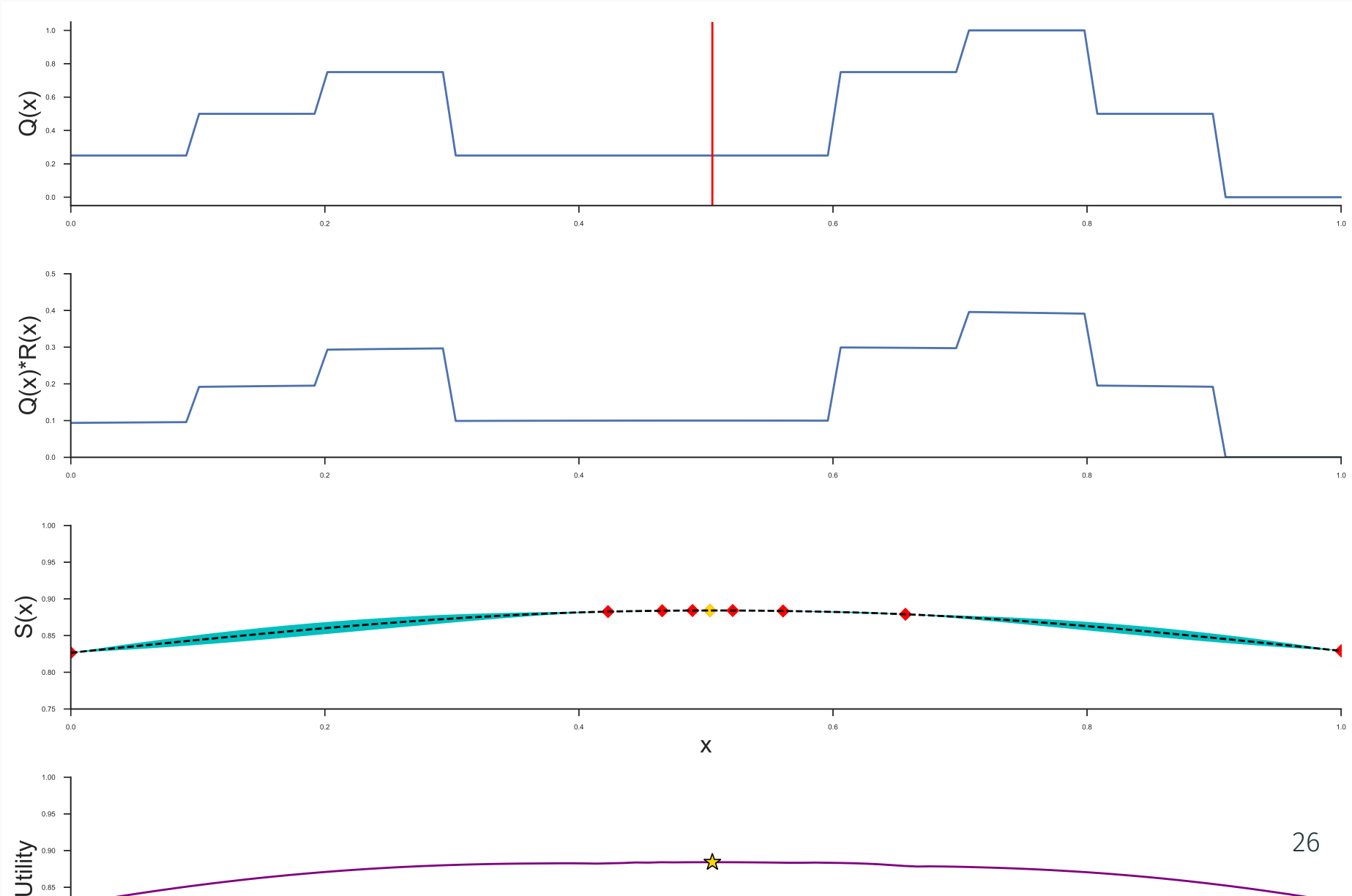
Bayesian optimization



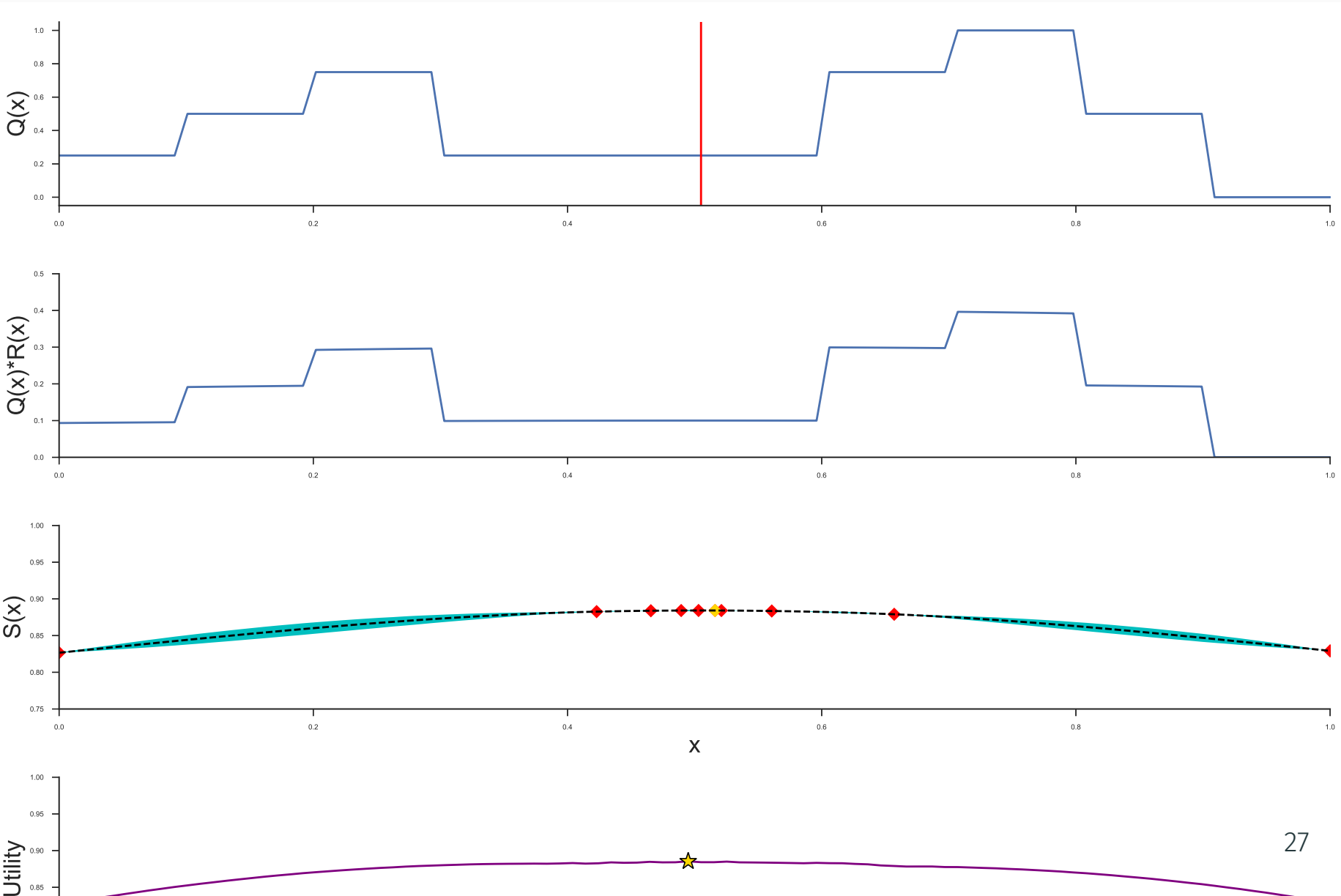
Bayesian optimization



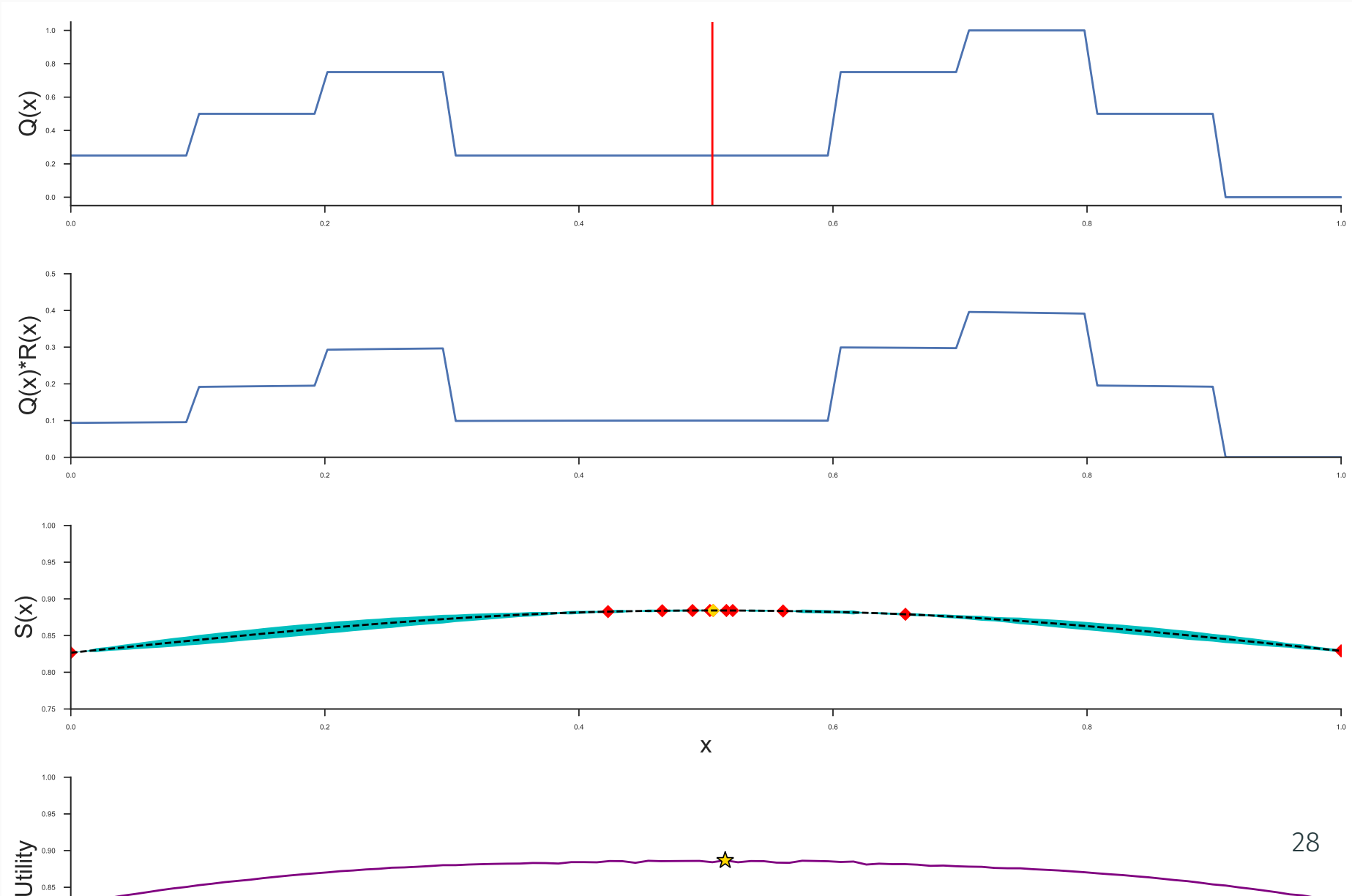
Bayesian optimization



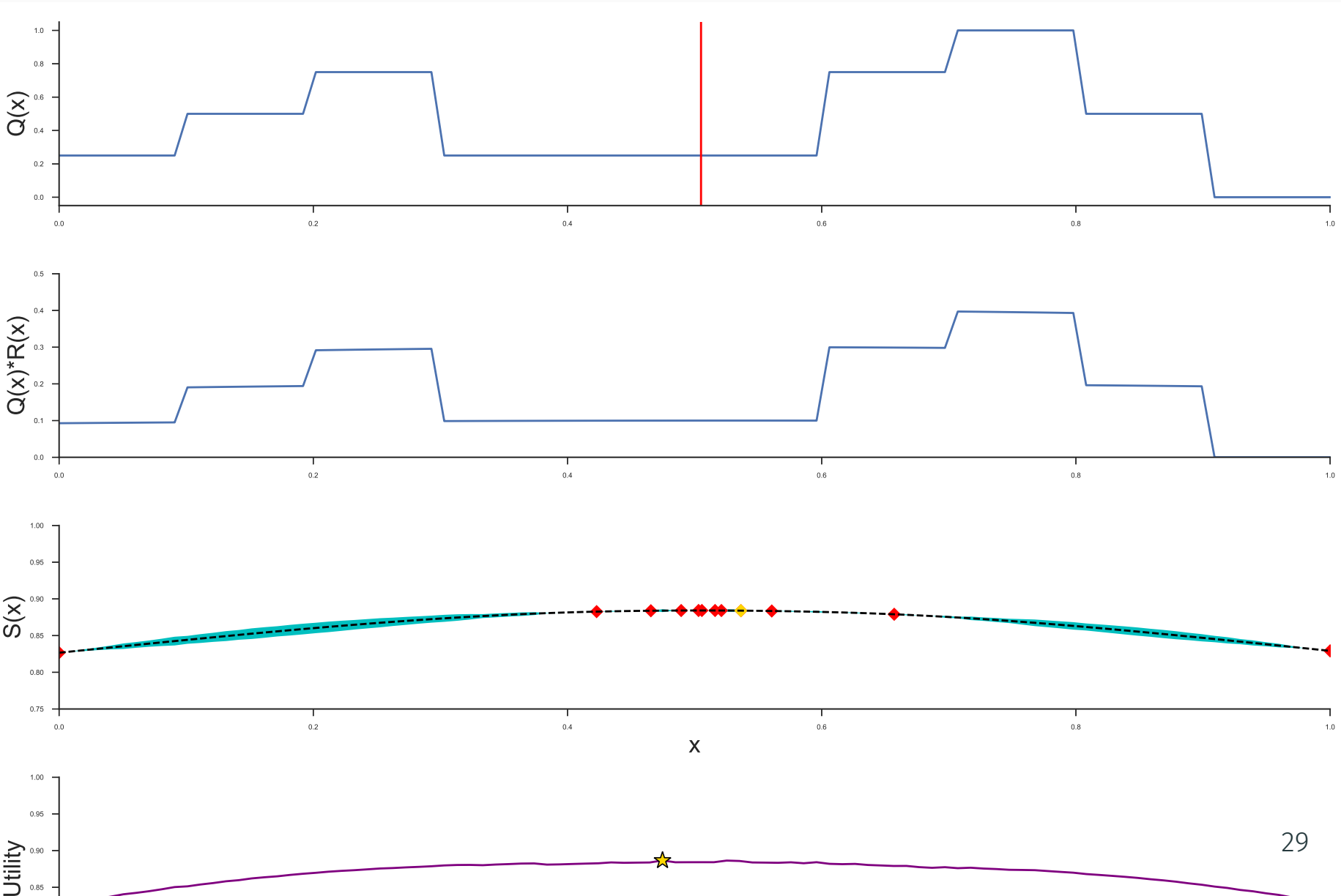
Bayesian optimization



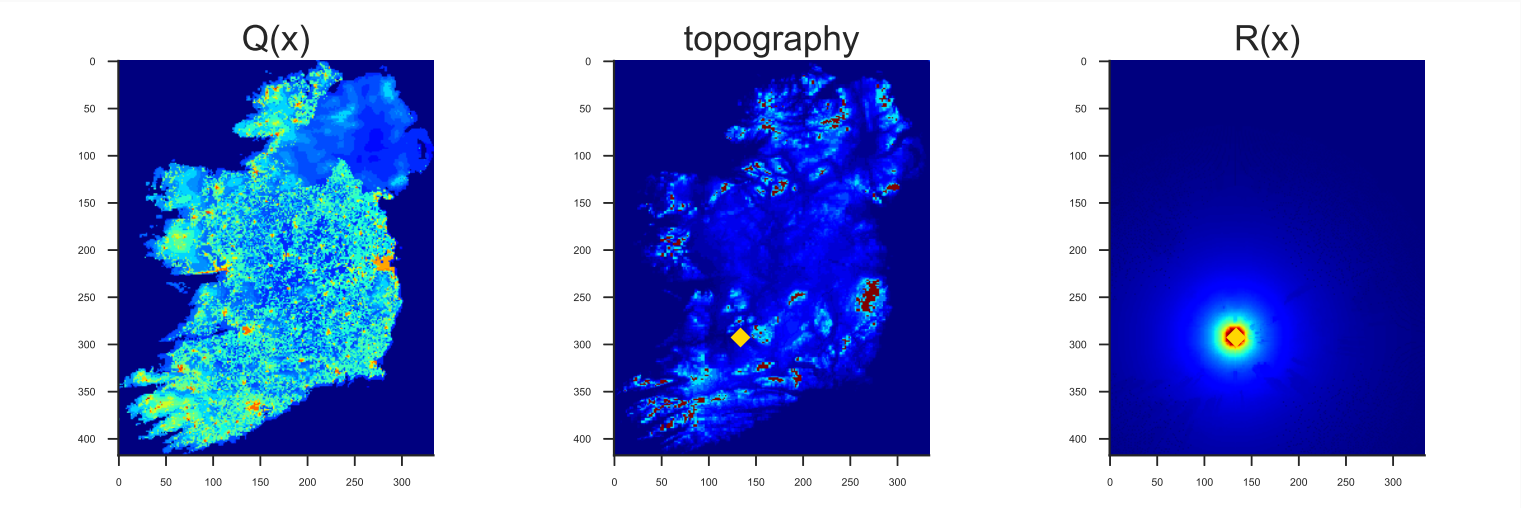
Bayesian optimization



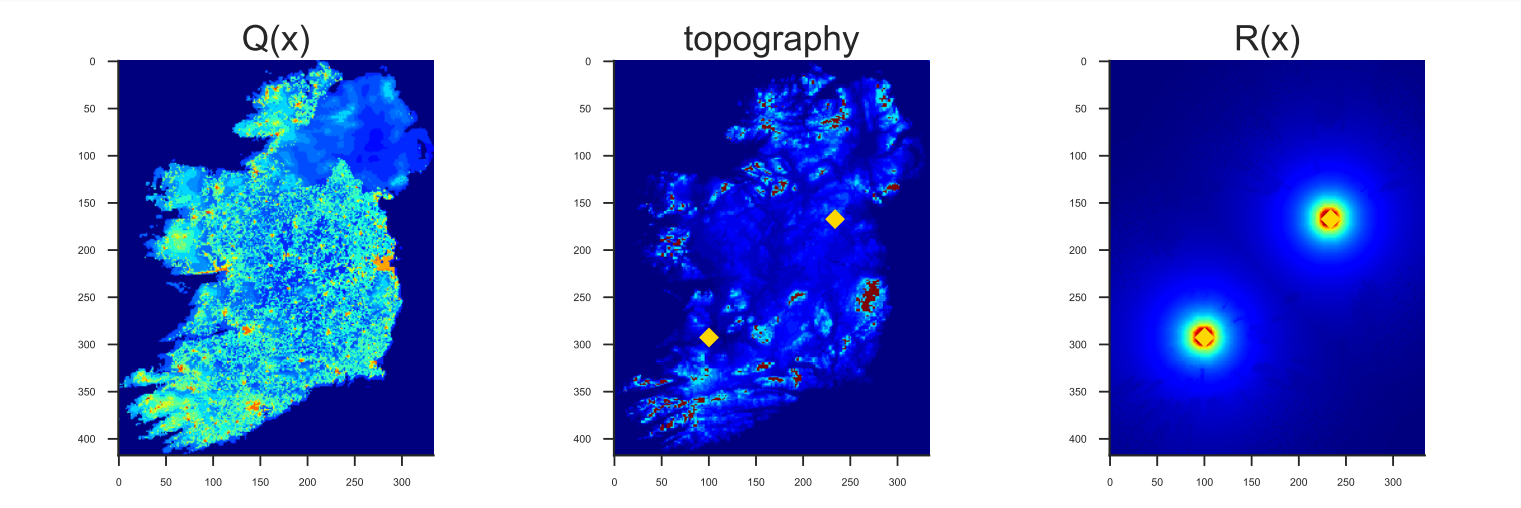
Bayesian optimization



Optimal locations



Optimal locations



In Summary...

- Optimal Radar positioning was found as shown on previous slide.
- With more time we could use a more refined grid to give even more accurate placement.
- This does give a guideline of how to improve Radar placement.

Sources of Data

Sources of Maps & Data:

- Population: Central Statistics Office of Ireland (www.cso.ie).
- Airport: SkyVector (www.skyvector.com), Irish Aviation Authority (www.iaa.ie).
- Rainfall: Met Eireann (www.met.ie).

Summary

- Design of a general procedure for tackling the problem
- History effect: if you're going to have *n* radars plan accordingly

Future work:

- Physically realistic radar decay function (try Bayesian?)
- Practical choice for factor weights
- Considering other factors