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Search Pattern Design Optimization for 2D Electronic Scanning Fixed Panel Radar

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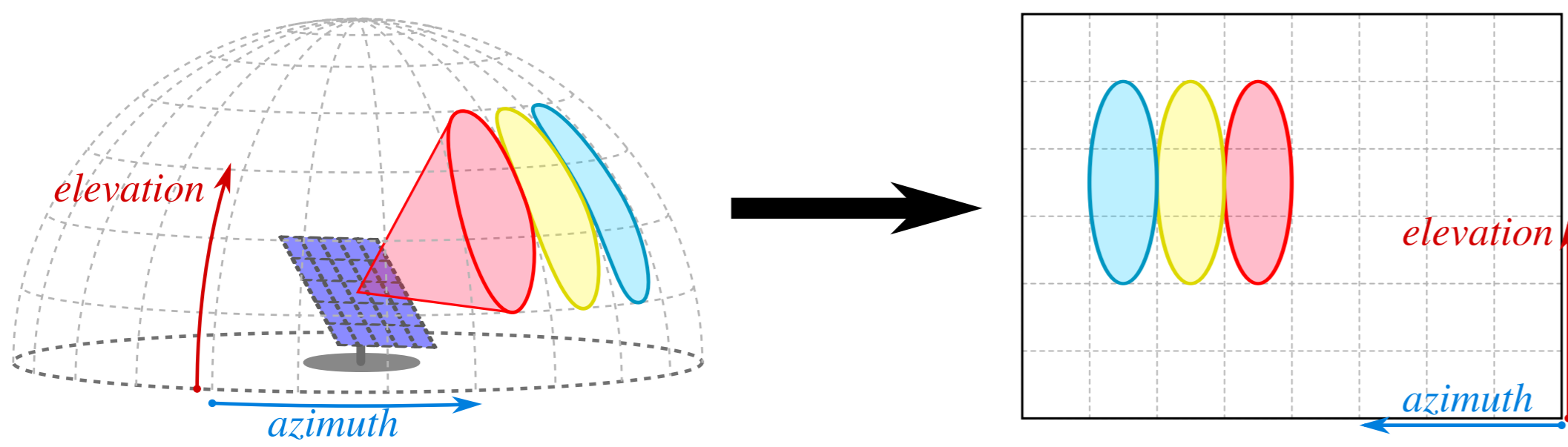
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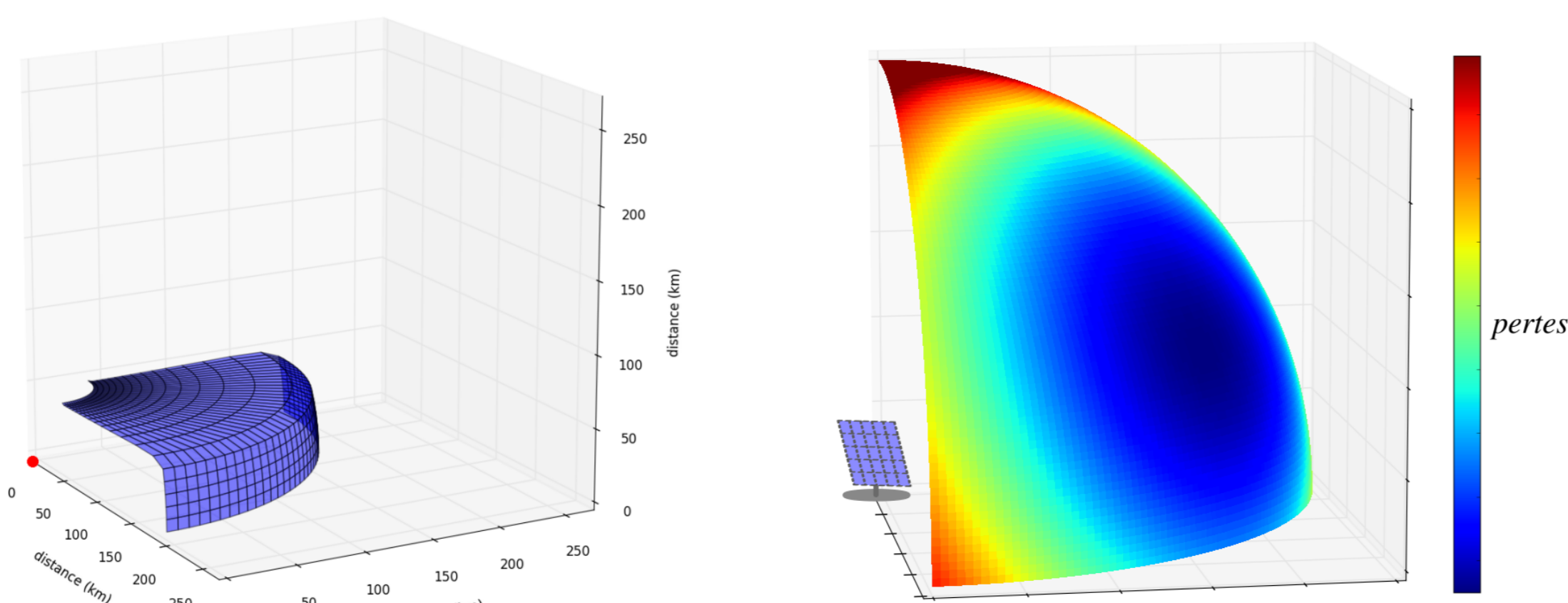
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1. Motivation & Methodology

Radar explores surrounding space by using a *search pattern*, ie a set of dwells



It must ensure detection at given range, using as low time budget as possible, and take into account anisotropic properties of the radar (deflection losses)



Currently, search patterns are hand-designed. Our objectives are to provide:

- ▶ a framework for algorithmic generation of optimized search patterns
- ▶ adaptive scanning for inhomogeneous environments (clutter, ridges, ...)

Methodology

- ▶ Definition of the radar model on a discrete grid.
- ▶ Formulation of the discrete model as an Integer Program
- ▶ Optimization by Linear Relaxation and Branch&Bound

3. Integer Program Formulation

Formulation of dwell cover as a binary vector

$$C_d = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{matrix} N \\ M \end{matrix}$$

For a given dwell d , at a given case (i, j) , dwell cover is defined by:

$$C_d(i, j) = \begin{cases} 1, & \text{if } E_d(i, j) \geq E_{req}(i, j) \\ 0, & \text{else} \end{cases}$$

and represents cases where detection complies with requirements.

Formulation of range constraints as a matrix inequality

We search a subset of dwells (among D feasible dwells) covering all cases. Having each case covered by at least one dwell is equivalent to the inequation

$$\begin{pmatrix} C_0(0,0) & \dots & C_D(0,0) \\ C_0(0,1) & \dots & C_D(0,1) \\ \vdots & \ddots & \vdots \\ C_0(m,n) & \dots & C_D(m,n) \end{pmatrix} \begin{matrix} D \\ \vdots \\ D \end{matrix} \geq \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} \Leftrightarrow \mathbf{A} \cdot \mathbf{x} \geq \mathbf{1}$$

where $x_d = 1$ if the dwell d is chosen, and 0 otherwise.

$\mathbf{x} = (x_0, \dots, x_D)$ is a binary encoding of a search pattern : $S = \{d_i, \text{ s.t. } x_i = 1\}$

Formulation of search pattern duration as a linear function

We wish to minimize the duration of the search pattern S , defined as :

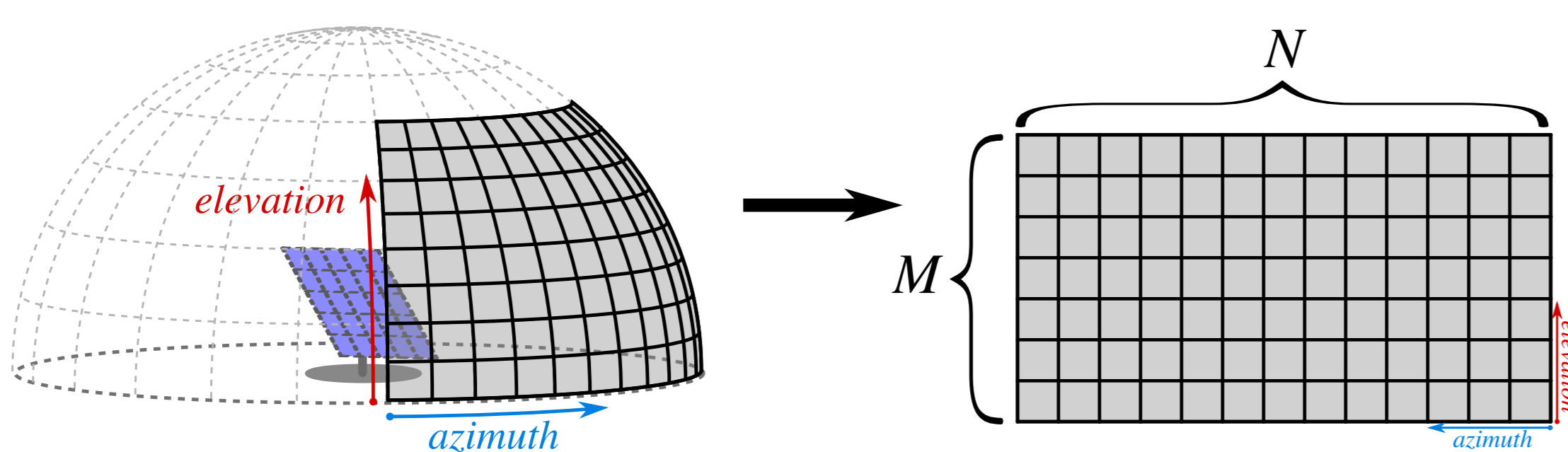
$$\sum_{d \in S} T_d = \sum_i x_i \cdot T_i = \mathbf{x} \cdot \mathbf{T}$$

with $\mathbf{T} = (T_0, \dots, T_D)$

2. Radar Model

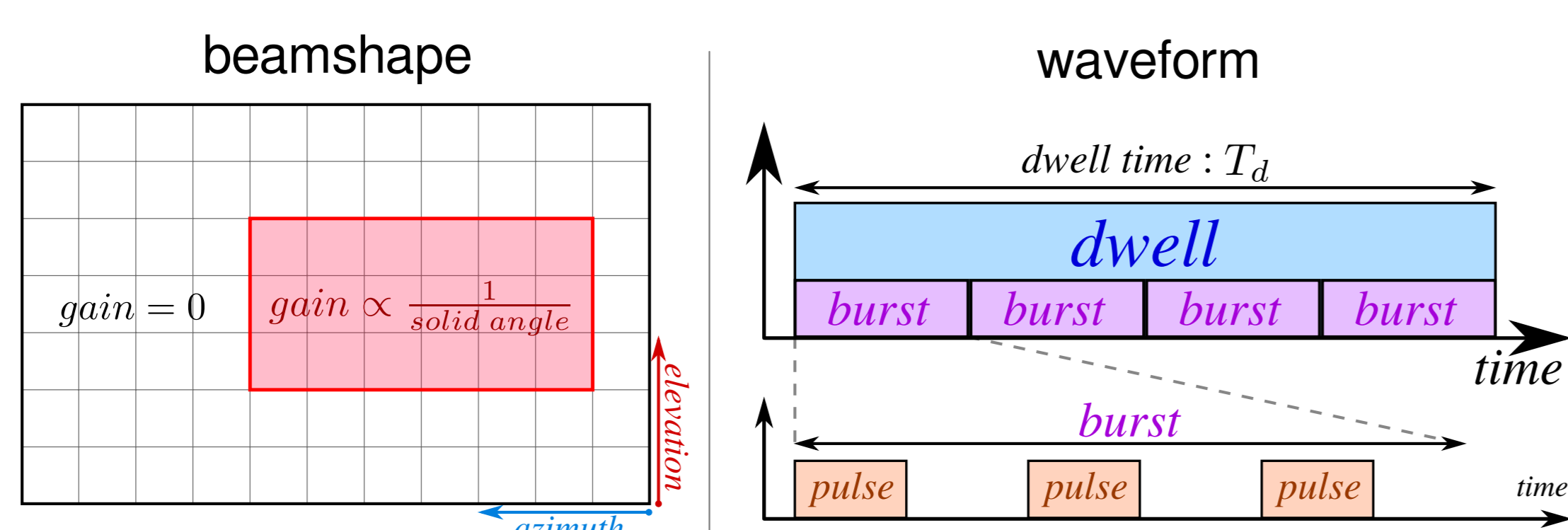
Discrete Radar space

Approximation of the region of interest by a $M \times N$ grid



Dwell (rectangular model)

Combination of beamshape (where it emits) and waveform (what it emits)



The set of potential dwells is the combination (Cartesian product) :

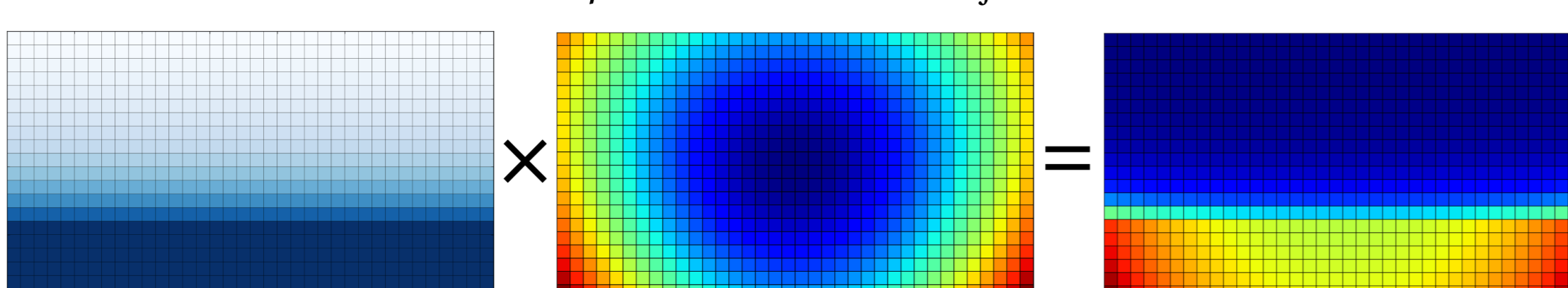
- ▶ All possible beamshapes, ie all possible subrectangles in the grid ($\approx \frac{M^2 N^2}{4}$)
- ▶ A set of W given waveforms : $\mathcal{W} = \{wf_1, wf_2, \dots, wf_W\}$.

Each wf_i associated to a duration T_i , and an energetic efficiency η_i

In practice, the set of feasible dwells is smaller :

- ▶ smallest beamshape : focalised beam \times deflection
- ▶ largest beamshape : limited by radar post-processing speed

"Energy" requirements : $E_{req} = Range^4 \cdot Loss_{defl}$

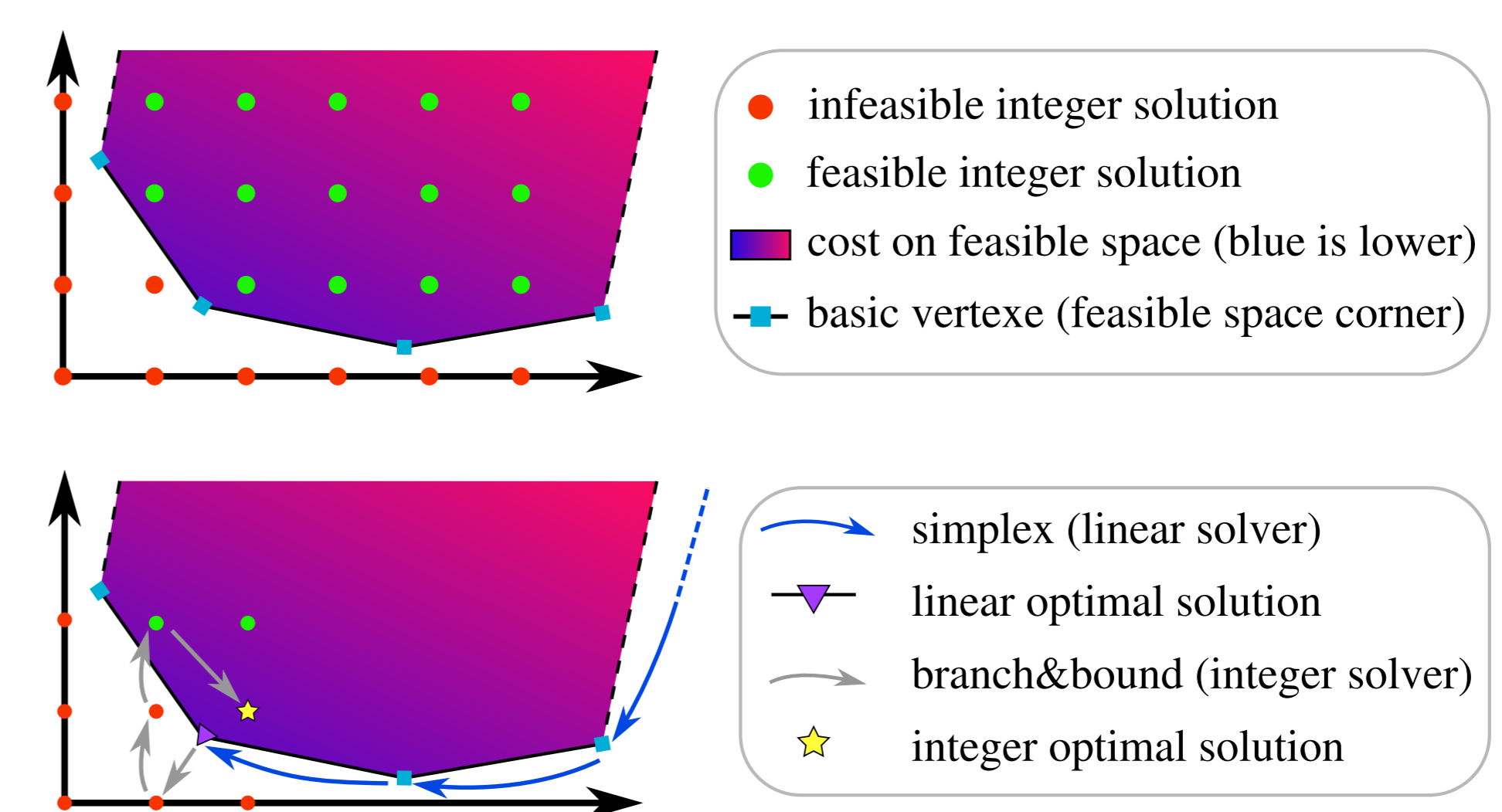


4. Optimization

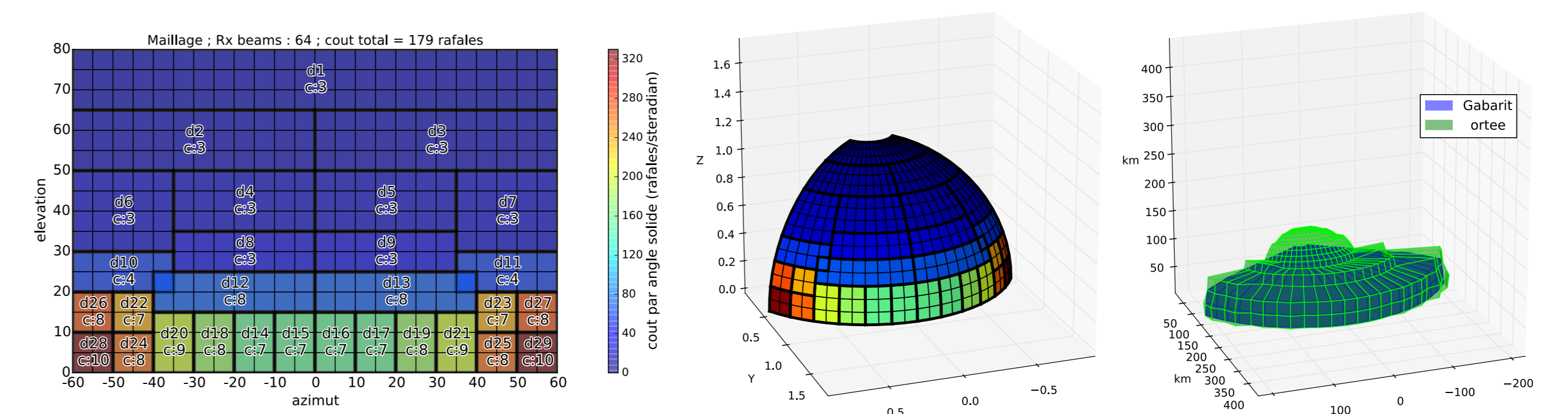
Minimization of search pattern duration under detection constraints

$$\begin{aligned} \min \quad & \mathbf{x} \cdot \mathbf{T} \\ \text{s.t.} \quad & \mathbf{A} \cdot \mathbf{x} \geq \mathbf{1} \\ & \mathbf{x} \in \{0, 1\}^D \end{aligned}$$

Solver (GLPK, MATLAB intlinprog) outline for Integer Programming



5. Results & Conclusion



Framework :

Advantages :

- ▶ Separates model from solver
- ▶ Integer linearity

Drawbacks :

- ▶ complexity \approx resolution⁵⁻⁶
- ▶ Discrete approximation

Perspectives

- ▶ 1. Study combinatorial structure of the problem. (Strongly NP ? Likely. Possibly reduced to bin packing).
- ▶ 2. Improve radar model : beamforming, waveform generation, etc.