Optimal Configuration of Compute Nodes for Synthetic Aperture Radar Processing

by

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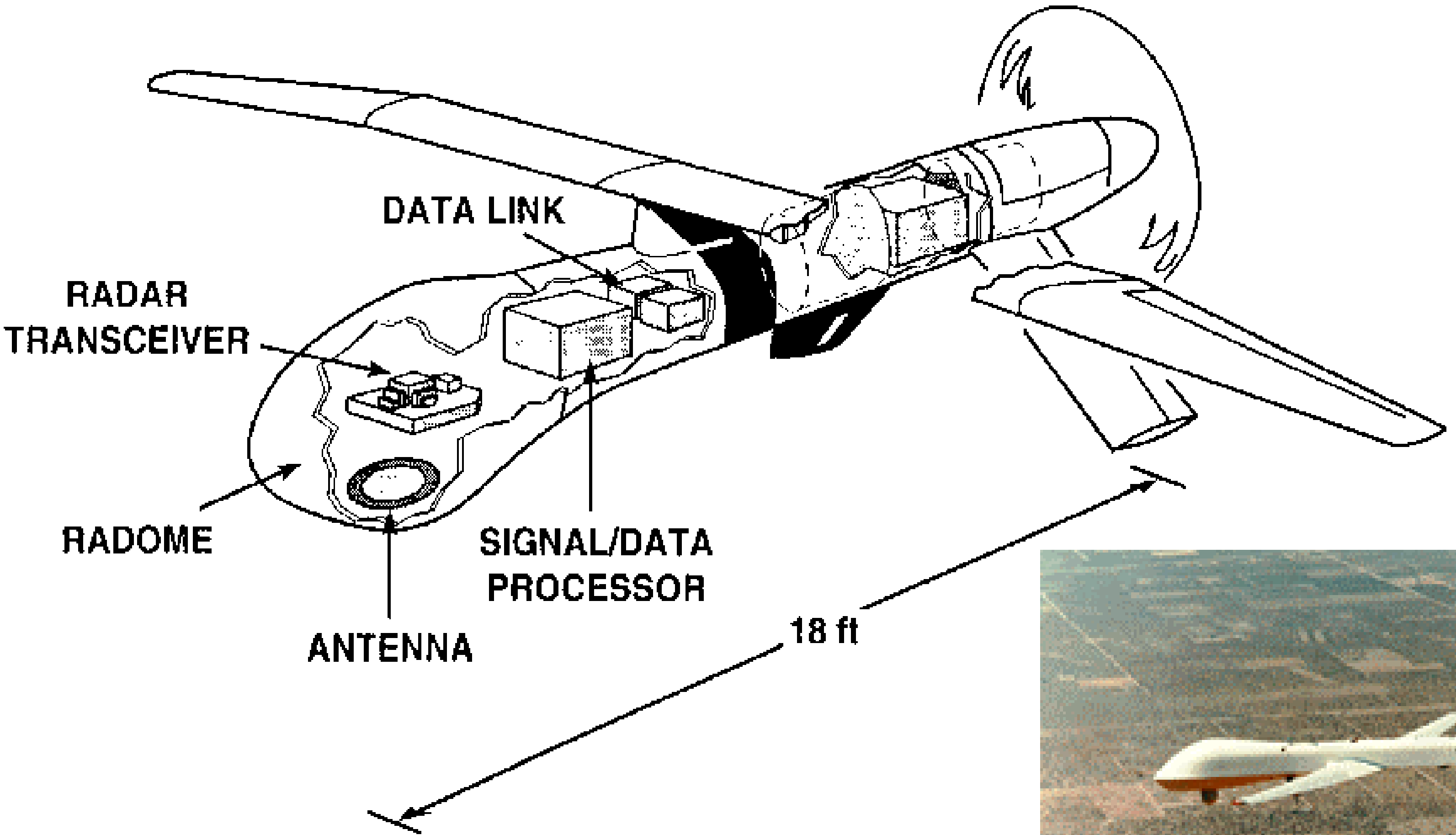
Outline

- **Motivation and SAR Basics**
- Parallelization of SAR Processing
- The Optimal Configuration Problem
  - Formulation
  - Numerical Results
- Conclusions

Motivation for Research and Key Terms

- **Embedded Systems**
- **High-Performance Computing**
- **DSPs**: Digital Signal Processors
- **GPPs**: General Purpose Processors
- **FPGAs**: Field Programmable Gate Arrays
- **COTS**: Commercial Off-the-Shelf
- **UAV**: Unmanned Aerial Vehicle
- **SWAP**: Size, Weight, and Power

Nominal UAV Payload



"Predator"

Synthetic Aperture Radar

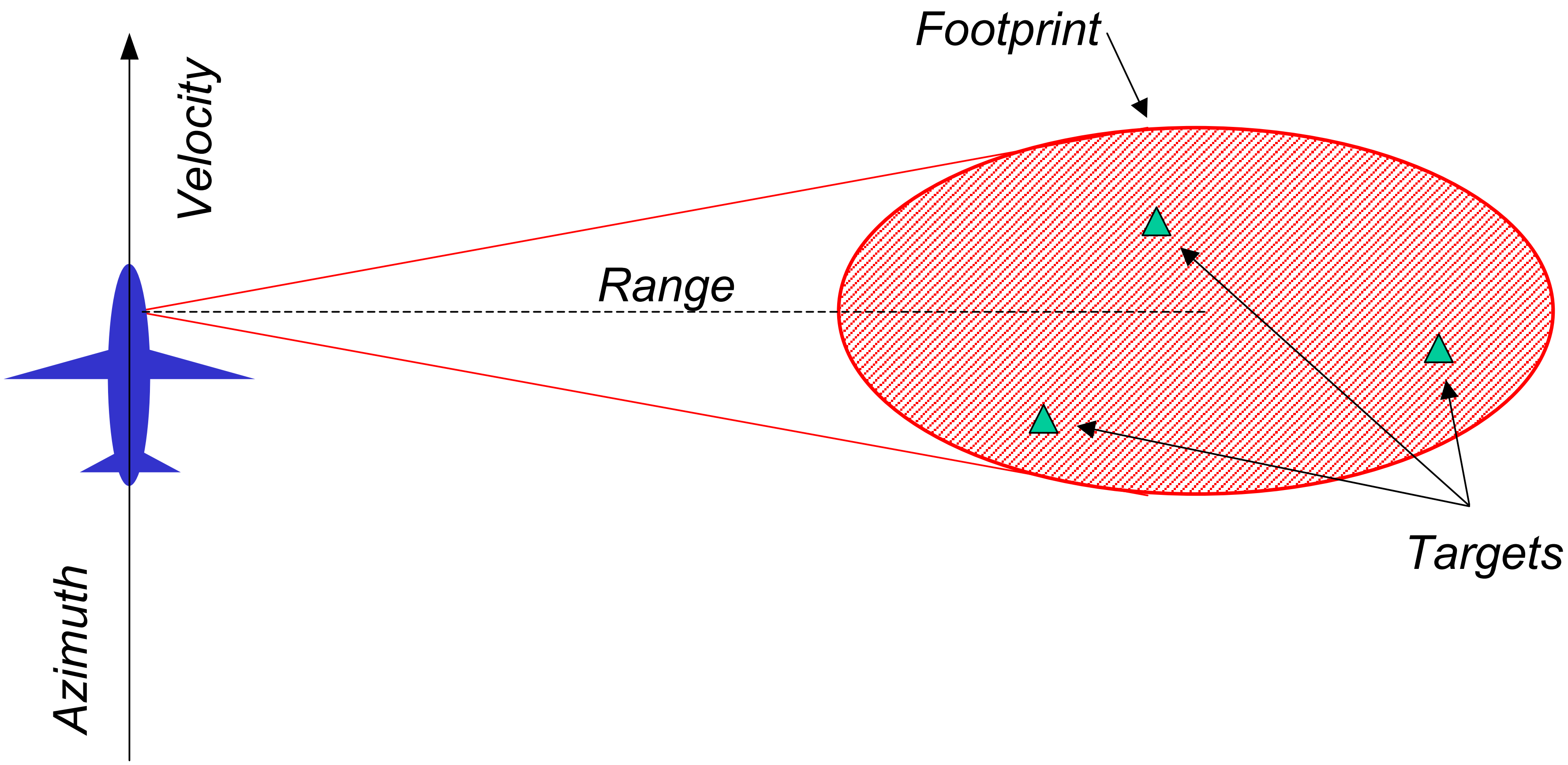
Uses:

- Ground surveillance
- Terrain and weather mapping
- Ocean current and ice floe tracking
- Detection of earthquake faults

Advantages over optical methods:

- Radio waves relatively unaffected by bad weather and poor lighting
- True 3-D images possible

Footprint of Aerial Side-Looking SAR



Pulse and Azimuth Compression

Pulse (Range):

- Based on bandwidth of FM chirp
- Resolution:

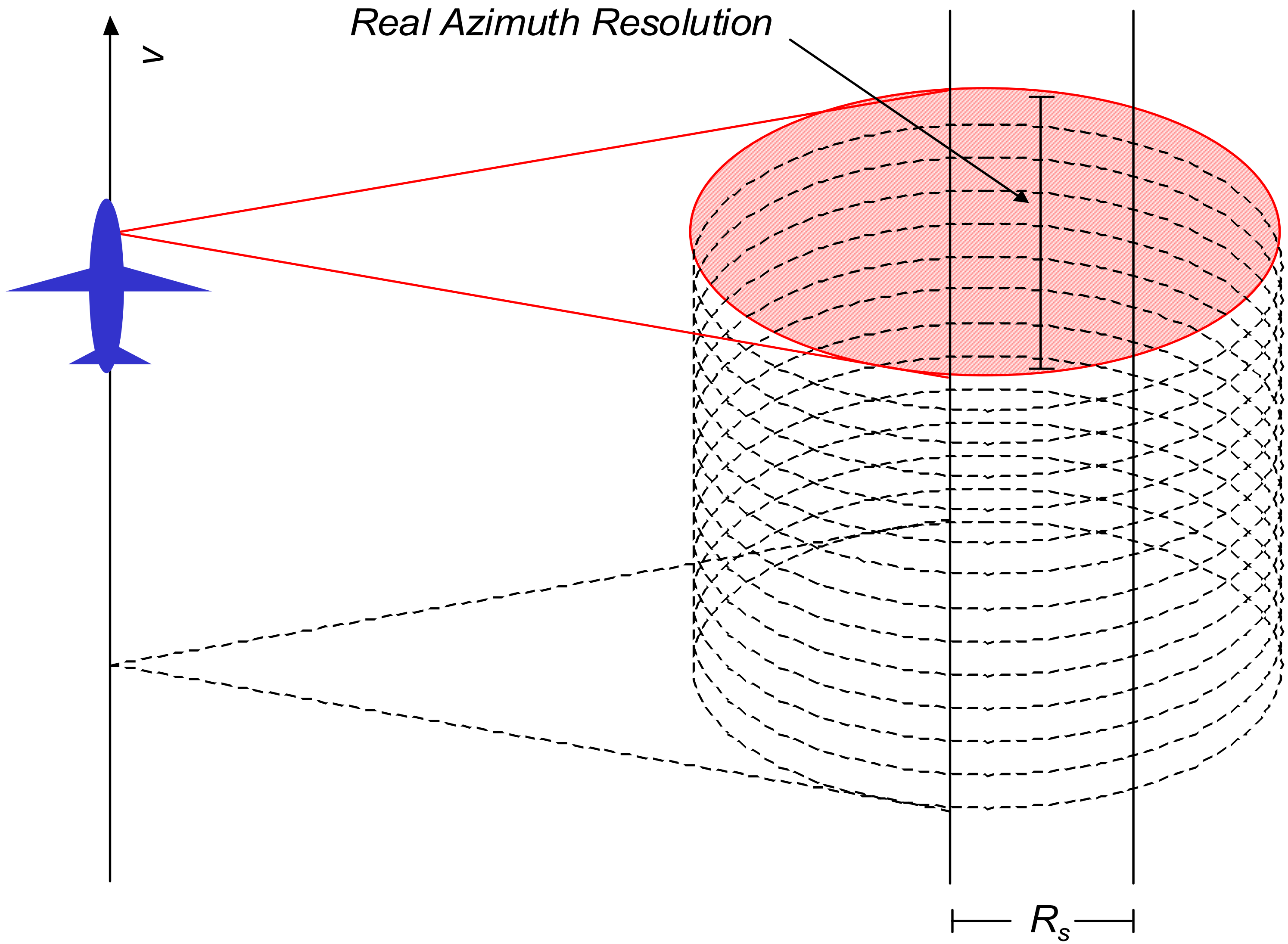
Uncompressed	Compressed
$\delta_R = \frac{c\tau_p}{2}$	$\delta_R = \frac{c}{2B}$

Azimuth:

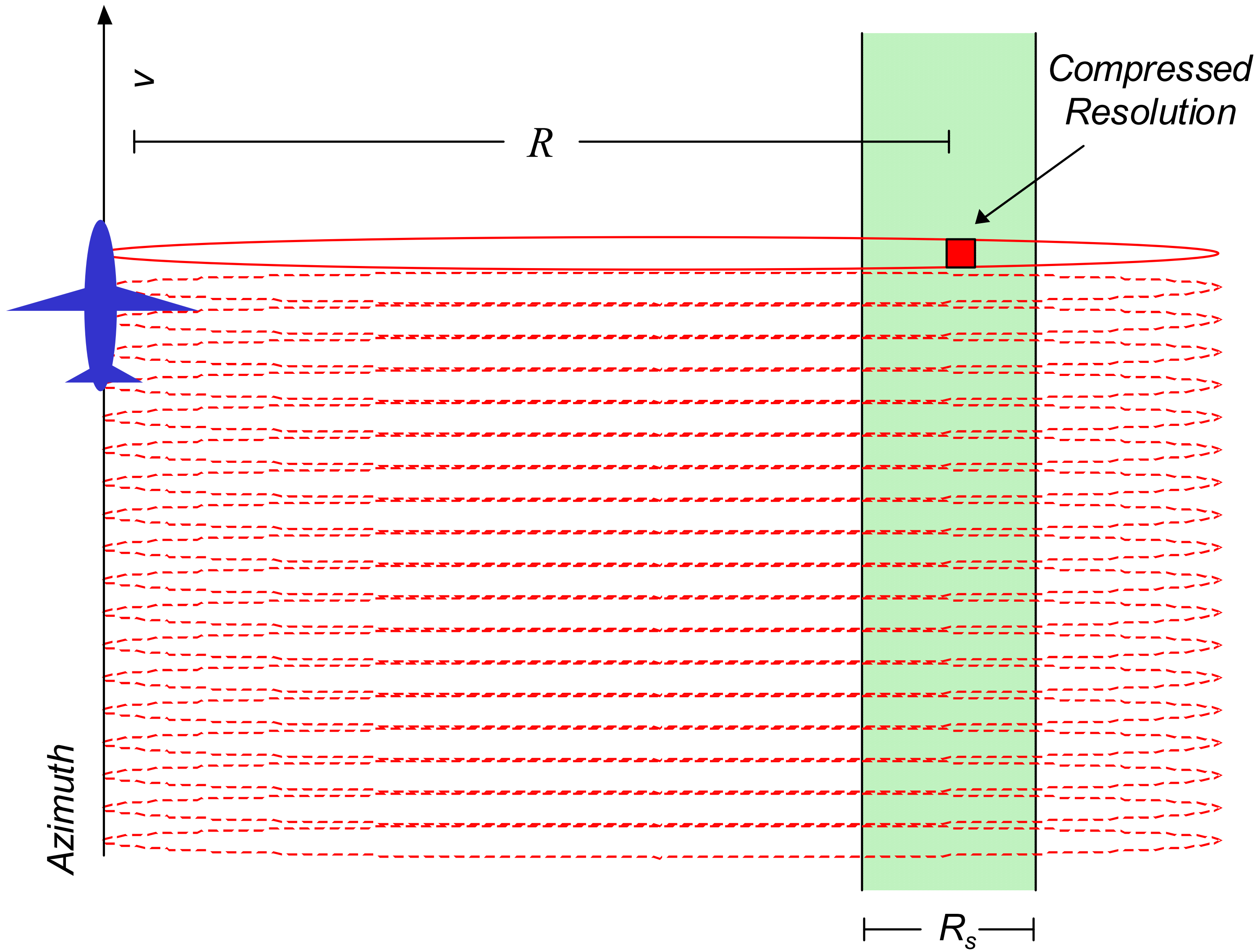
- Based on Doppler frequency shift
- Resolution:

Uncompressed	Compressed
$\delta_{Az} \approx \frac{R\lambda}{A}$	$\delta_{Az} = \frac{A}{2}$

Offset Overlapping Beams



Synthetic Beams



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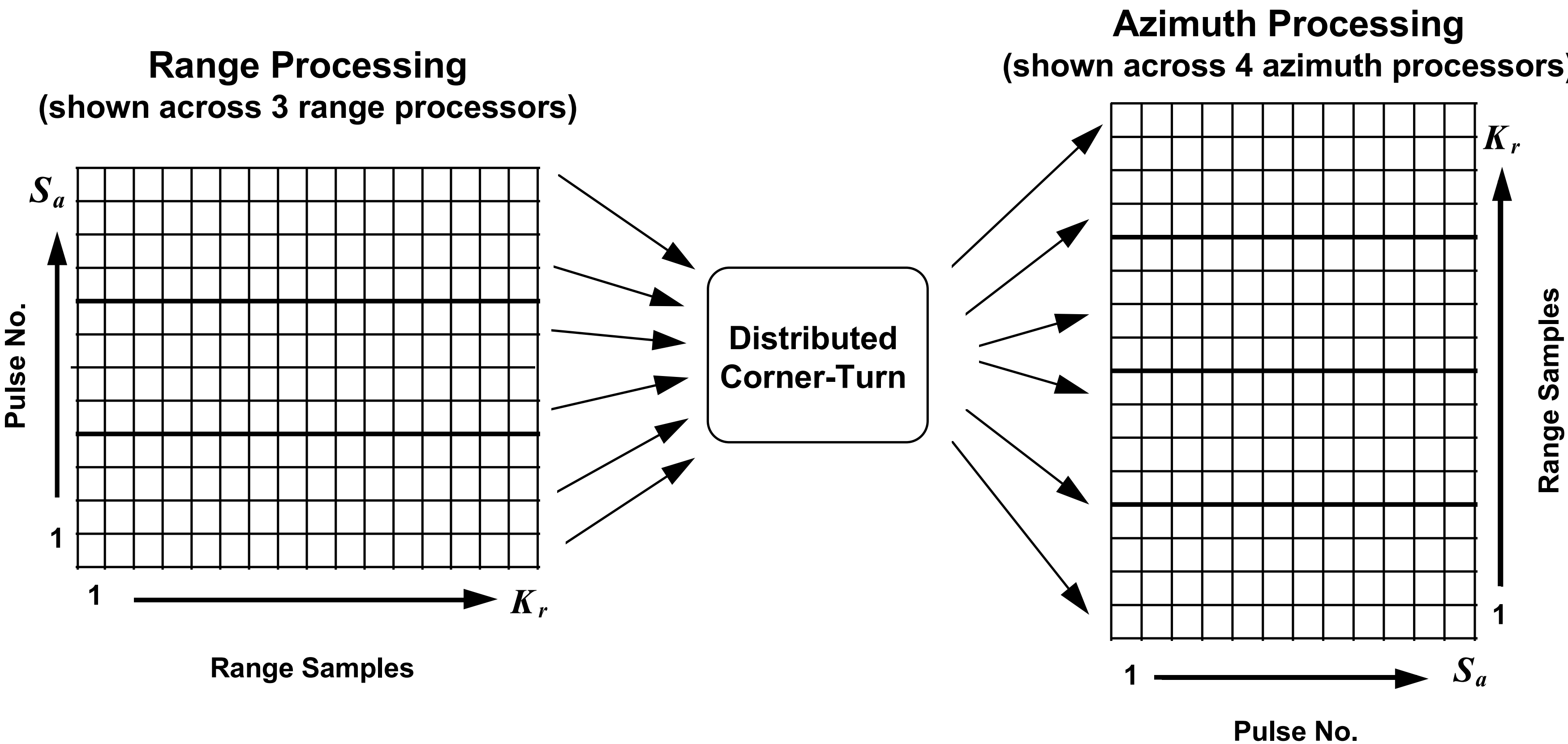
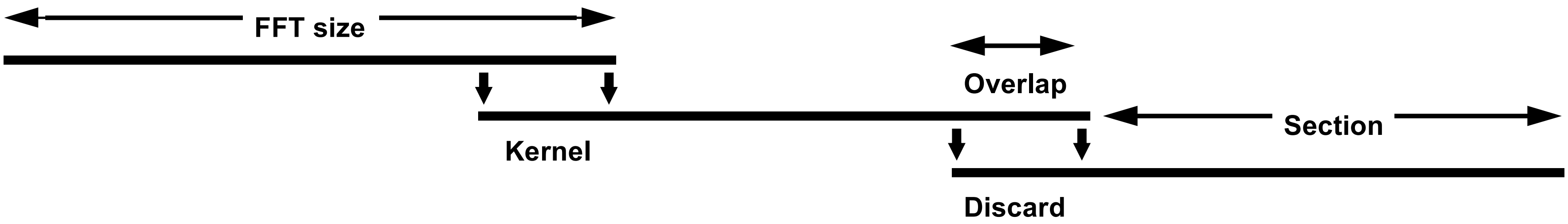
Parallelization of SAR Processing



where S_a is the azimuth section length and K_r is the range reference kernel size

Reference: T. Einstein, "Realtime Synthetic Aperture Radar Processing on the RACE Multicomputer," App. Note 203.0, Mercury Computing Sys, 1996.

Sectioned Convolution



Large Overlap/Section ratio ⇒ Small azimuth memory, large number azimuth processors
Small Overlap/Section ratio ⇒ Large azimuth memory, small number azimuth processors

Reference: T. Einstein, "Realtime Synthetic Aperture Radar Processing on the RACE Multicomputer," App. Note 203.0, Mercury Computing Sys, 1996.

System Parameters

- **radar-dependent:** R (range), R_s (range swath), and λ (wavelength)
- **application-dependent:** δ (desired resolution) and v (platform velocity)
- **processor-dependent:** α_r and α_a (non-fast-convolution range and azimuth loading) and γ (fast convolution throughput)
- **software-dependent:** S_a (azimuth convolution section length), F_a (azimuth FFT length), and F_r (range FFT length)

Derivations for Memory and Processor Requirements

$$P_r = \frac{v(6\delta F_r + \alpha_r \gamma R_s + 10\delta F_r \lg F_r)}{\gamma \delta^2}$$

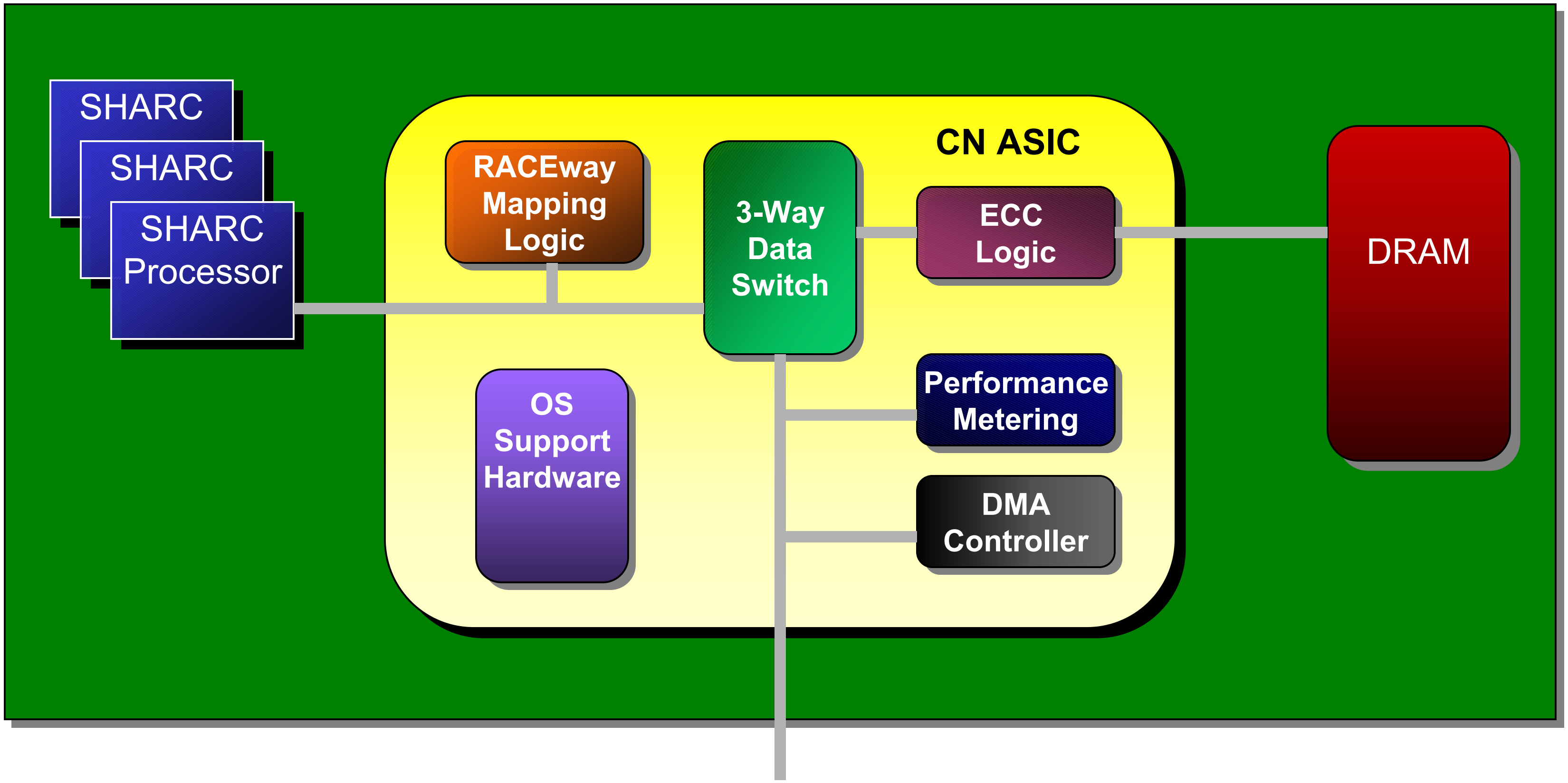
$$P_a = \frac{vR_s\left(\alpha_a + \dfrac{F_a(6 + 10\lg F_a)}{\gamma S_a}\right)}{\delta^2}$$

$$M_r = \frac{16R_s v(6\delta F_r + \alpha_r \gamma R_s + 10\delta F_r \lg F_r)}{\gamma \delta^3}$$

$$M_a = \frac{R_s(\lambda R + 2\delta^2 S_a)}{\delta^3}$$

where P_r and P_a are the number of required processors and M_r and M_a are the memory requirements in Mbytes for range and azimuth processing, respectively

SHARC Compute Node Architecture



RACEway Interface

Daughtercard Types

Type 1:

- 2 CNs/card
- 6 CEs/card
- 3 CEs/CN
- 32 MB DRAM/card
- 16 MB DRAM/CN
- 5.33 MB DRAM/CE
- 12.2 Watts

Type 2:

- 1 CN/card
- 2 CEs/card
- 2 CEs/CN
- 64 MB DRAM/card
- 64 MB DRAM/CN
- 32 MB DRAM/CE
- 9.6 Watts

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Optimal Configuration Formulation

- Based on characteristics of CNs:
  - Power consumption
  - Number of CEs
  - Amount of memory

- CEs are assigned to perform either range or azimuth processing.

- Processed data for a CE must be stored locally for both range and azimuth computations.

Optimal Configuration Formulation

- **Objective:** Determine configurations for the CNs, number of CNs of each configuration, and section size, to satisfy processor and memory requirements and minimize power consumption

- **Notation and Definitions:**
  - CN Configuration: Specifies the daughtercard type and number of range and azimuth CEs (per configured CN)
  - X, Y: The two possible CN configurations
  - X_T, Y_T: Daughtercard type for each CN configuration

Optimal Configuration Formulation

- **Notation and Definitions:**
  - X_r, Y_r: Number of range processors per CN (for each configuration)
  - X_a, Y_a: Number of azimuth processors per CN (for each configuration)
  - N_X, N_Y: Number of CNs of configurations X and Y
  - $\Pi_{CN}(\bullet)$: Power per CN as a function of daughtercard type
  - $M_{CN}(\bullet)$: Memory per CN as a function of daughtercard type
  - $P_{CN}(\bullet)$: Processors per CN as a function of daughtercard type

Optimal Configuration Formulation

Minimize:

$$Z = N_X \Pi_{CN}(X_T) + N_Y \Pi_{CN}(Y_T)$$

Subject to:

$$P_r \le N_X X_r + N_Y Y_r$$

$$P_a(S_a) \le N_X X_a + N_Y Y_a$$

$$M_{CN}(X_T) \ge X_r \frac{M_r}{P_r} + X_a \frac{M_a(S_a)}{P_a(S_a)}$$

$$M_{CN}(Y_T) \ge Y_r \frac{M_r}{P_r} + Y_a \frac{M_a(S_a)}{P_a(S_a)}$$

$$X_r + X_a \le P_{CN}(X_T)$$

$$Y_r + Y_a \le P_{CN}(Y_T)$$

$$F_a = 2^k \ge S_a + K_a, \qquad k = 1,2,....$$

$$N_X, N_Y, X_r, X_a, Y_r, Y_a \ge 0, S_a \ge 1$$

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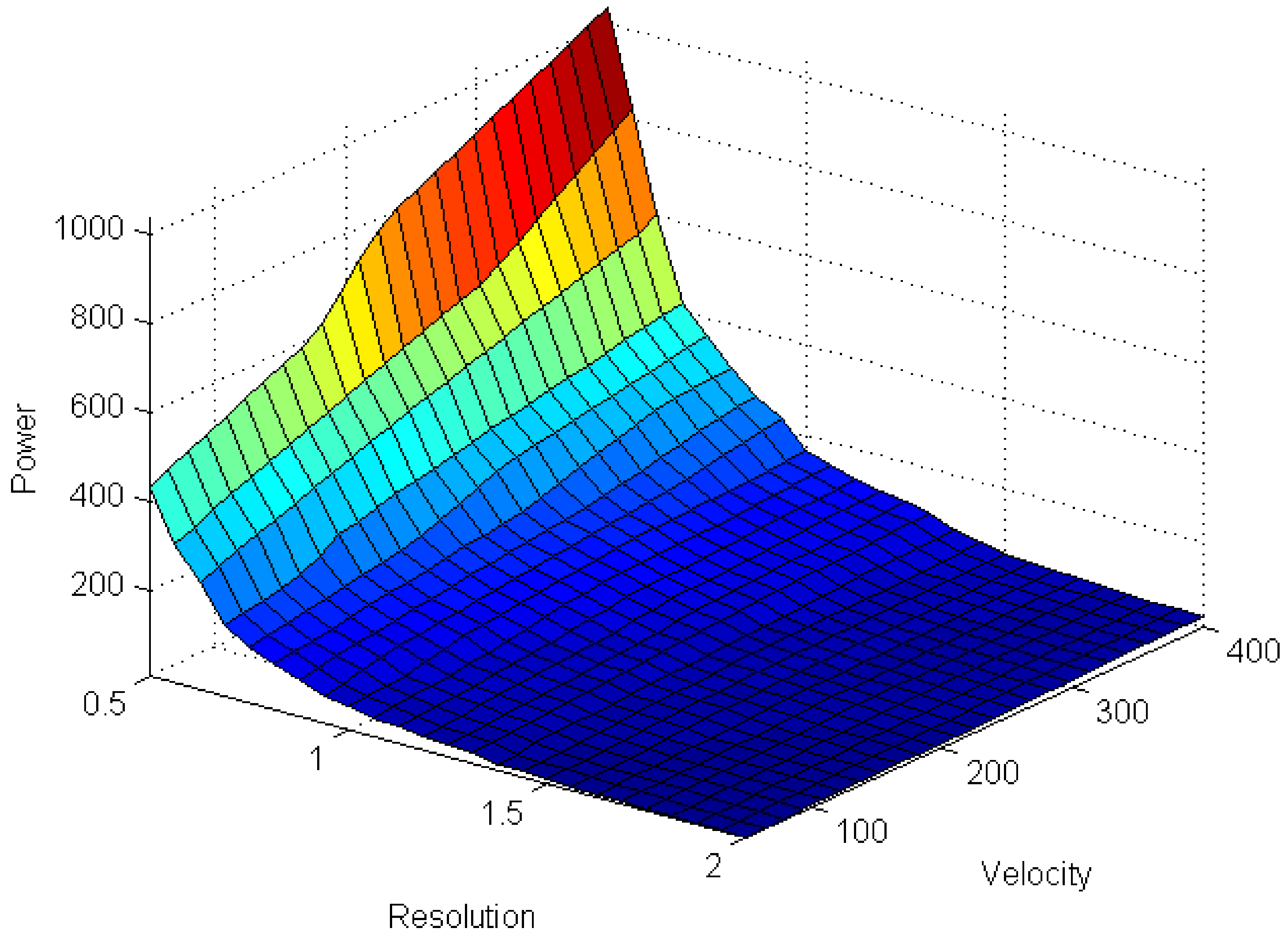
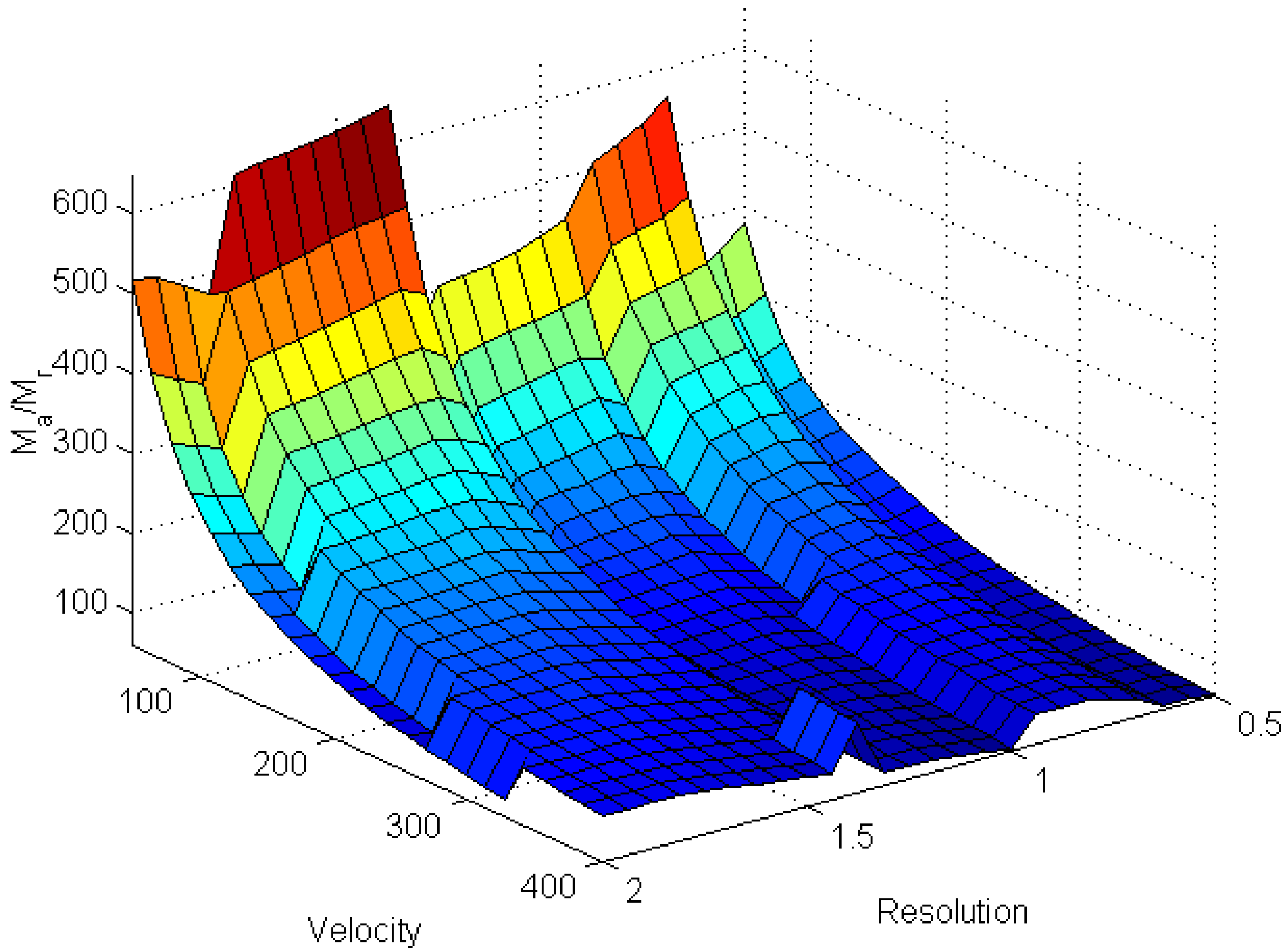
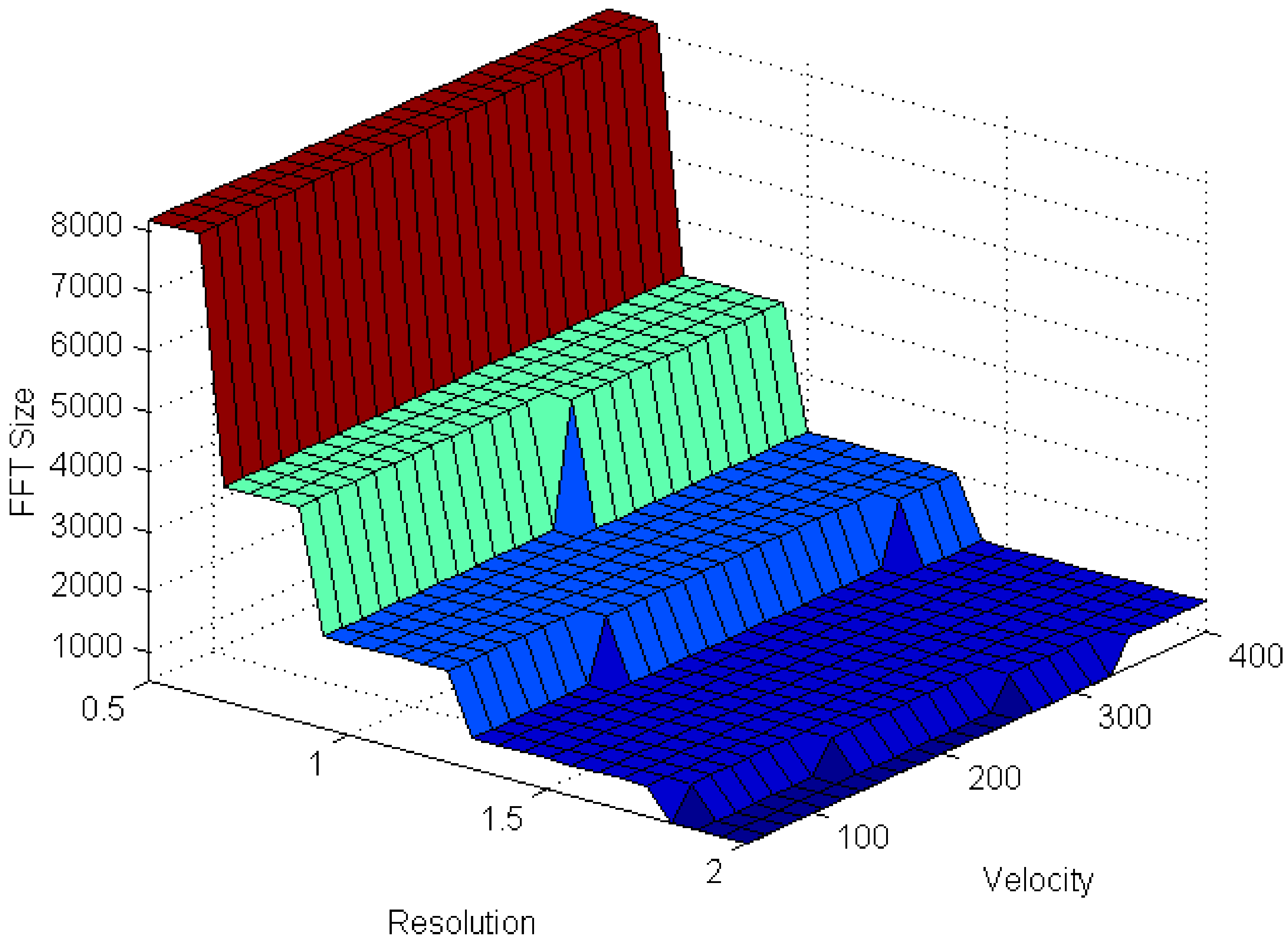
Minimum Power



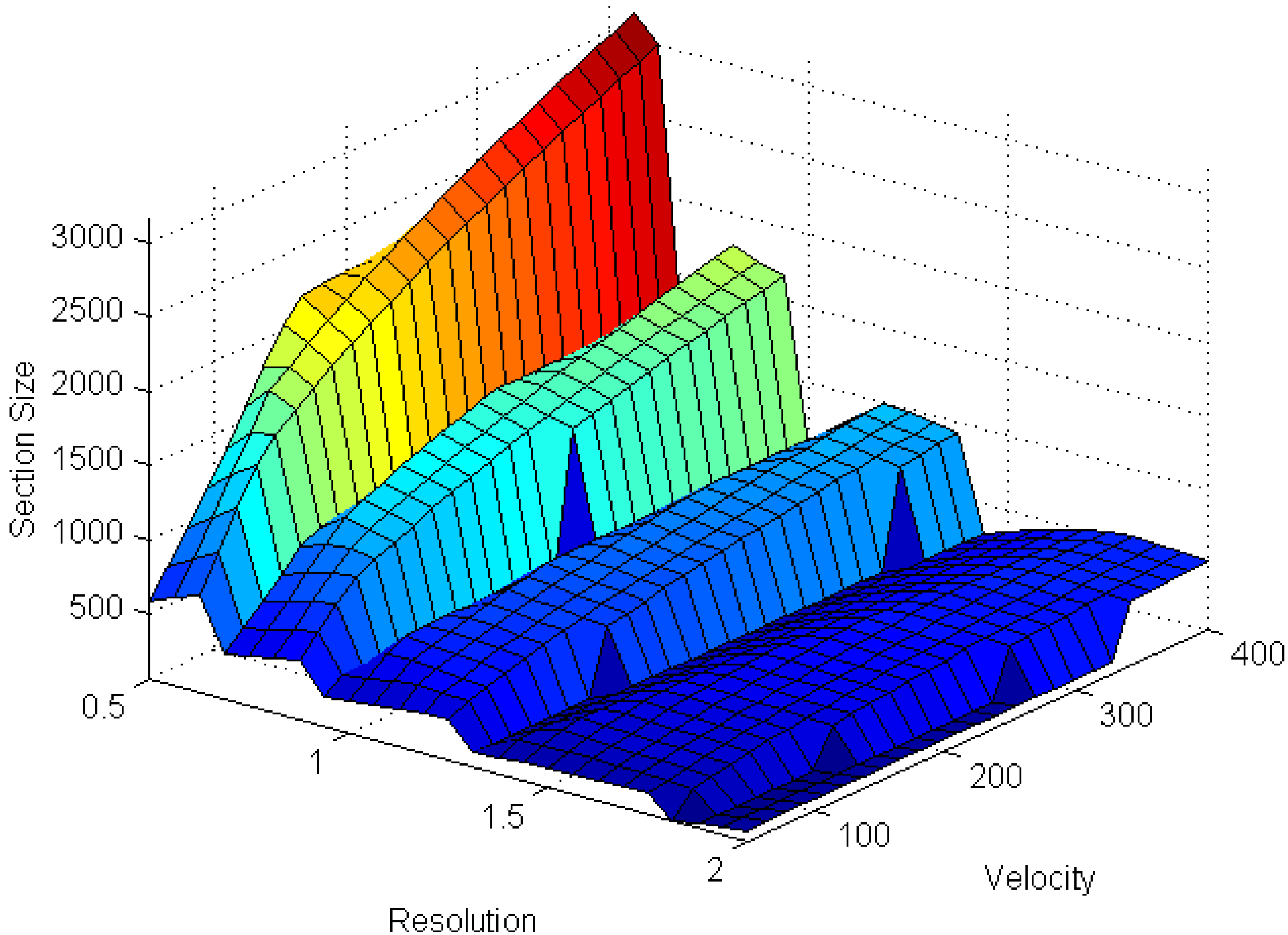
Ratio of Azimuth to Range Memory



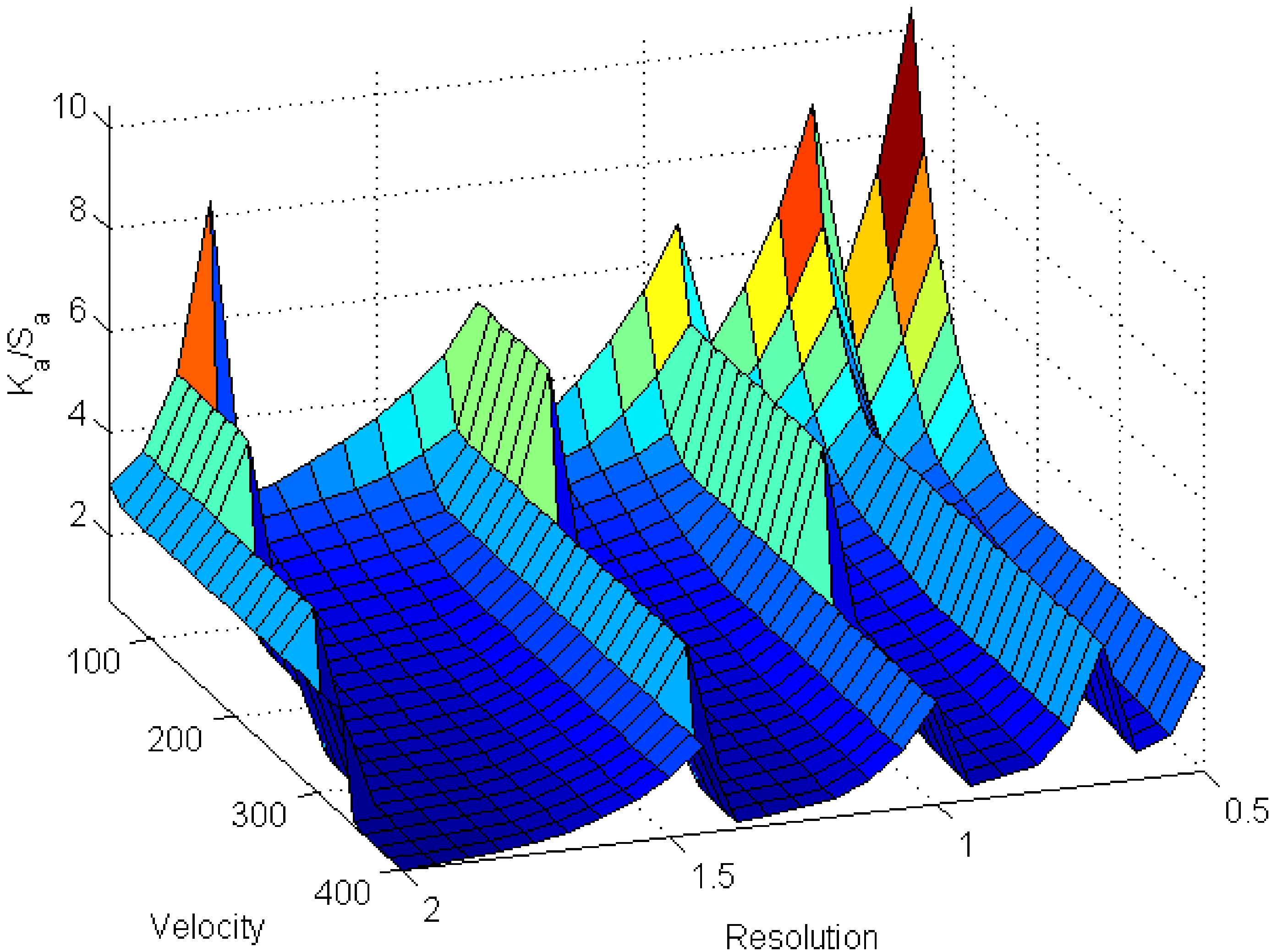
Azimuth FFT Size



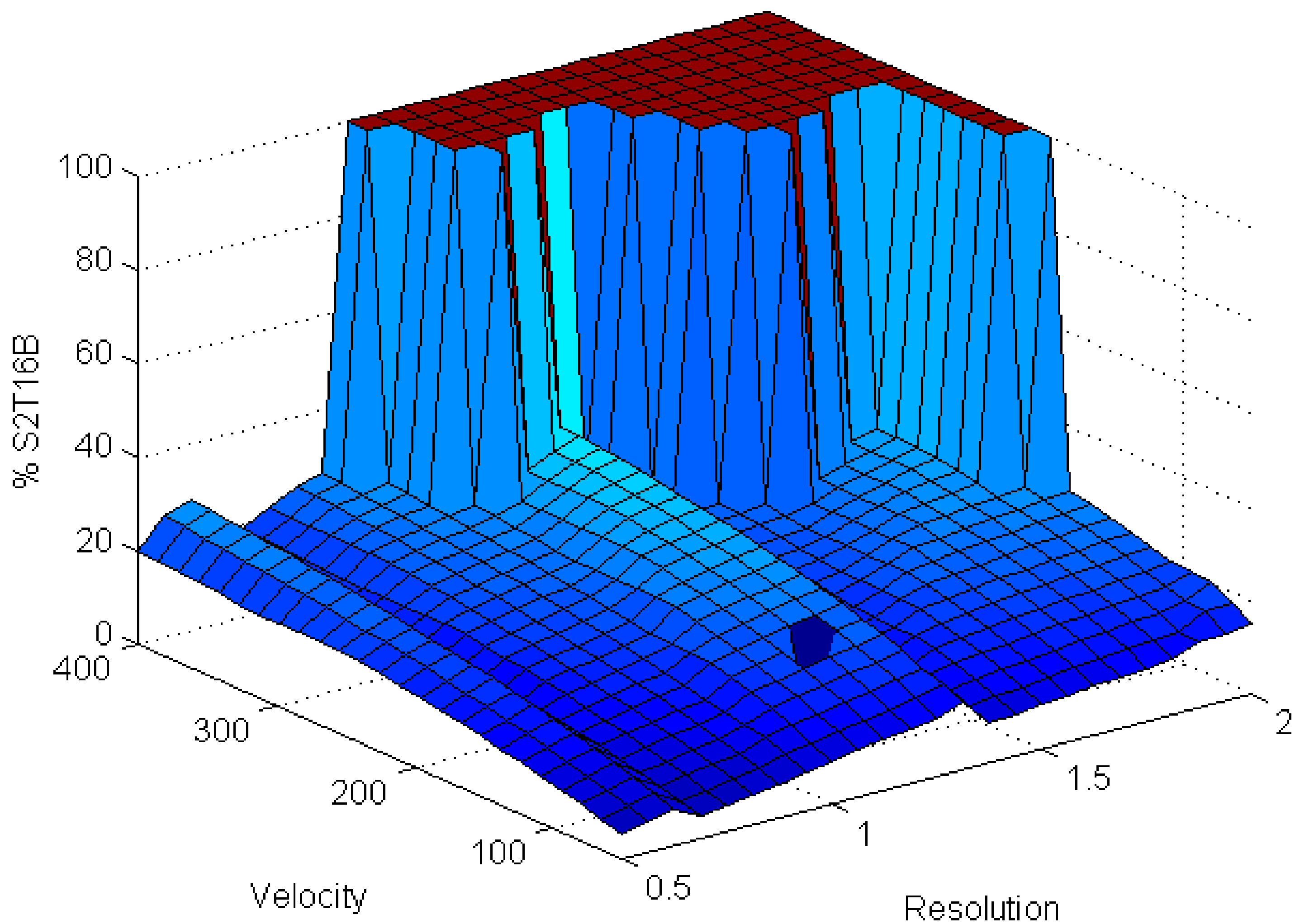
Optimal Azimuth Section Size



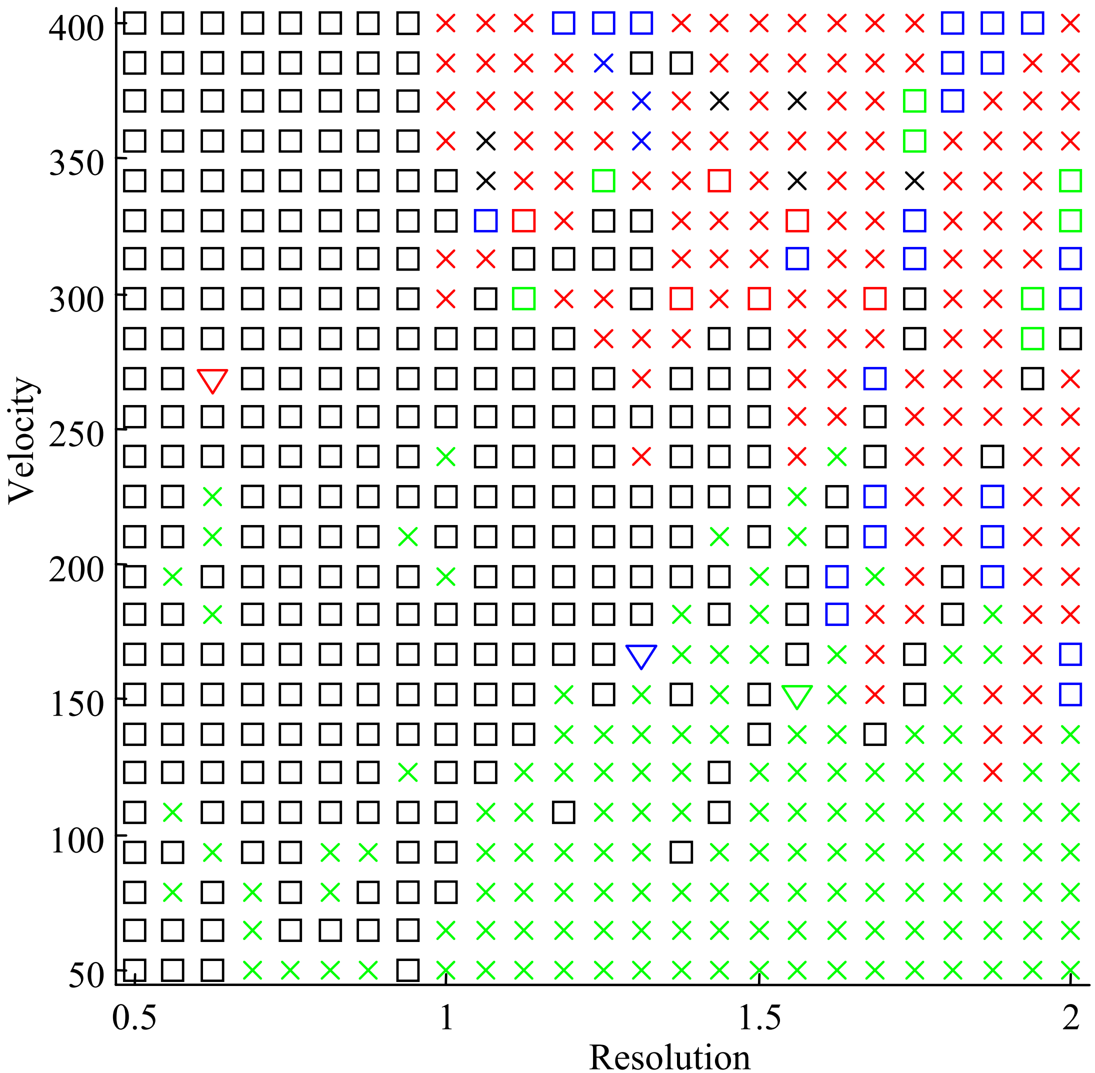
Optimal Ratio of Kernel Size to Section Size



Percentage of Power Usage by Card Type 1

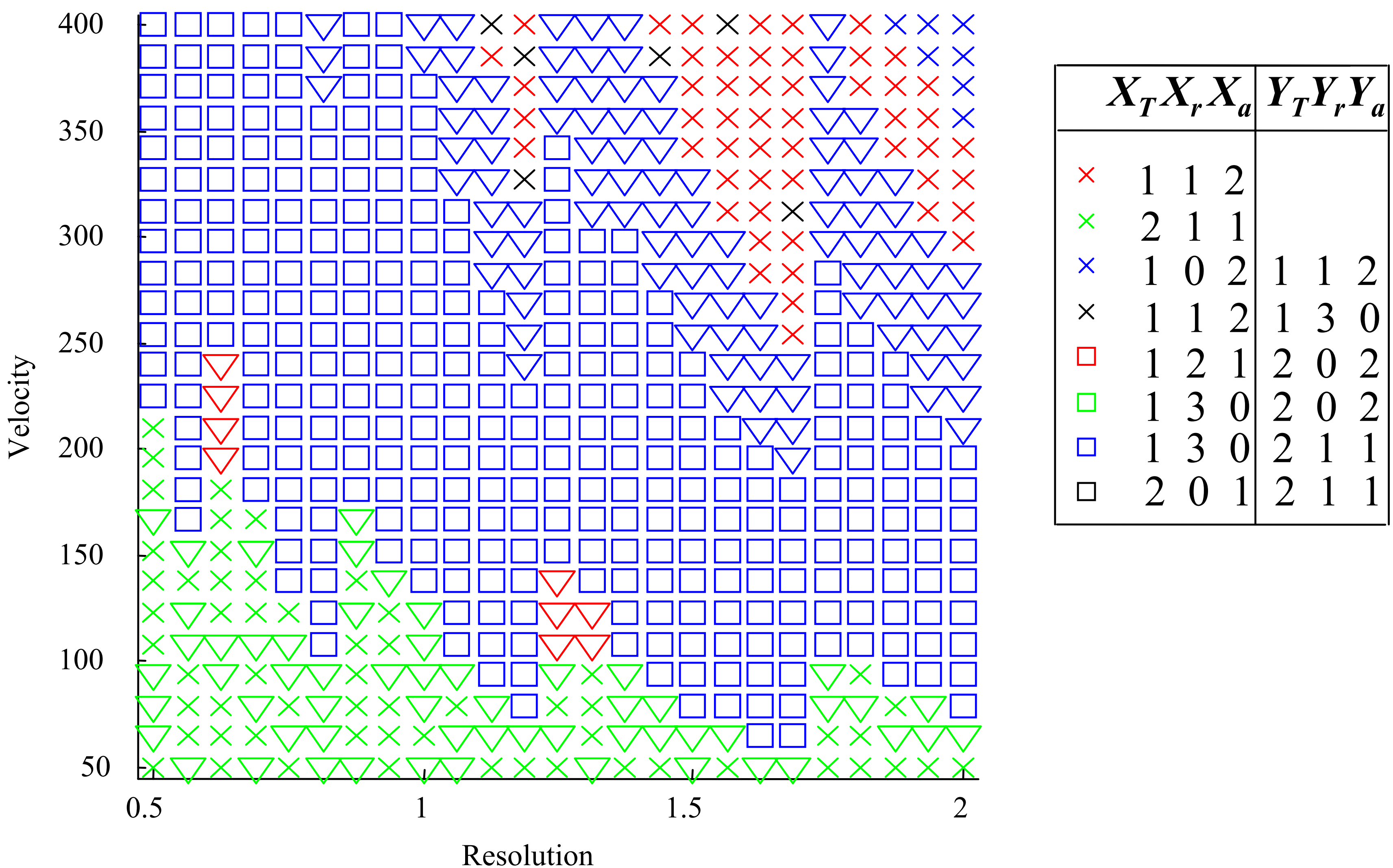


Optimal CN Configurations

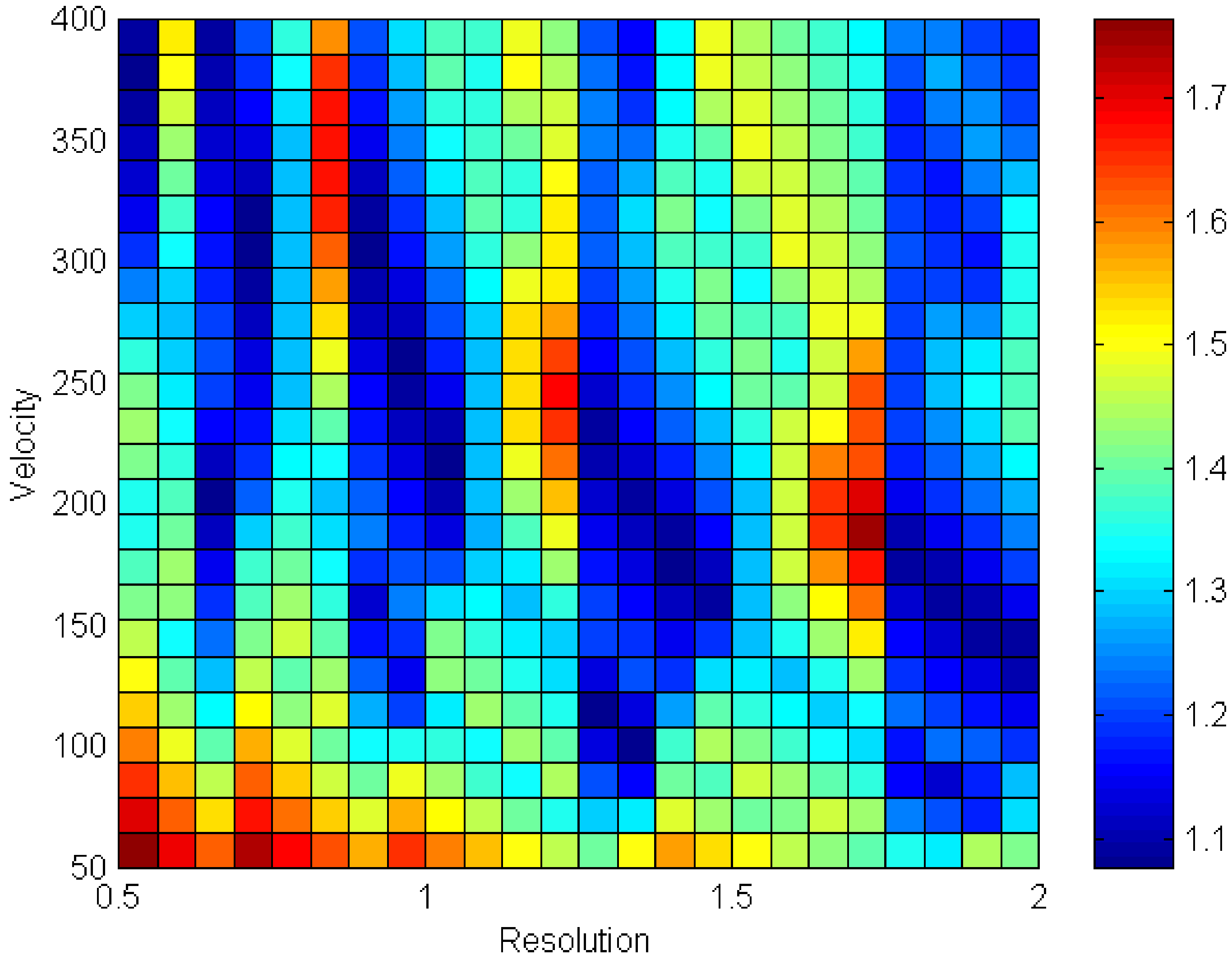


	$X_T X_r X_a$	$Y_T Y_r Y_a$
× (red)	1 1 2	
× (green)	2 1 1	
× (blue)	1 1 2	1 2 1
× (black)	1 1 2	2 0 1
□ (red)	1 1 2	2 0 2
□ (green)	1 1 2	2 1 1
□ (blue)	1 2 1	2 0 2
□ (black)	1 3 0	2 0 2
▽ (red)	1 3 0	2 1 1
▽ (green)	2 0 2	2 1 1
▽ (blue)	2 1 1	2 2 0

Sophisticated Nominal CN Configuration



Ratio of Nominal to Optimal Power



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Conclusions

- A method for optimally configuring CN-based parallel systems for SAR processing was introduced.
- The method provides detailed HW and SW design and implementation information about how to best utilize system resources for given values of application parameters.
- The numerical studies show that the optimal ratio of daughtercard types can be relatively constant over regions of the application parameter space.
- For a fixed hardware configuration, the CNs can be re-configured (via software re-configuration) to achieve optimal power consumption over specified regions.