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Problem. Solved.

A Streaming Sensor Challenge Problem for Ubiquitous High Performance Computing

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Ubiquitous High Performance Computing

- DARPA program to develop next generation of energy-efficient high throughput computers
- Nominal goals: 1 petaflop, 50 gigaflops/watt Linpack, 1 cabinet, 57KW whole system
- Modular and scalable: embedded to cabinet
- Complete goals TBD based on Defense needs

Ubiquitous High Performance Computing: CHASM

OBJECTIVE

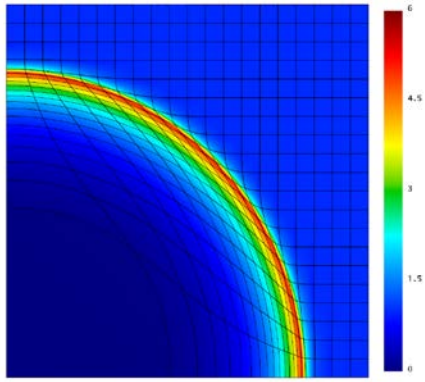
Drive the focus of UHPC architecture designs toward scalable capability on defense applications.

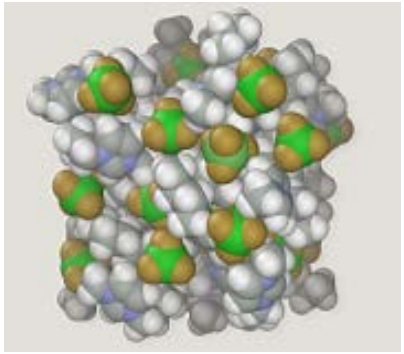
SUMMARY

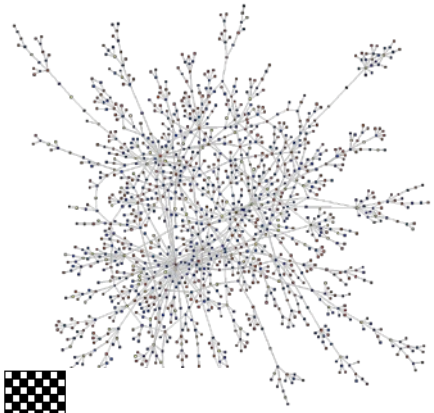
The CHASM team is designing challenge problems that embody the computing needs of 2018 defense missions, and developing new execution models that can support million-way parallelism and maintain performance with frequent faults.

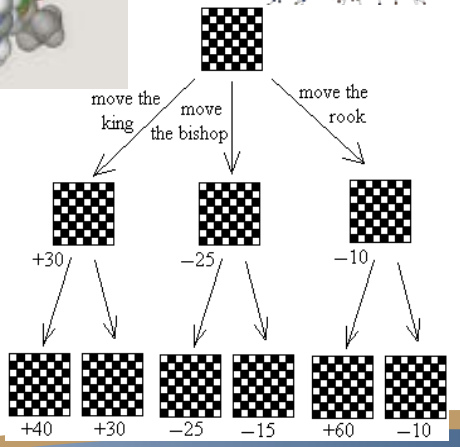
PARTNERS

- GT College of Computing
- GT Electrical and Computer Engineering
- Louisiana State University
- Lawrence Livermore National Laboratory
- Oak Ridge National Laboratory









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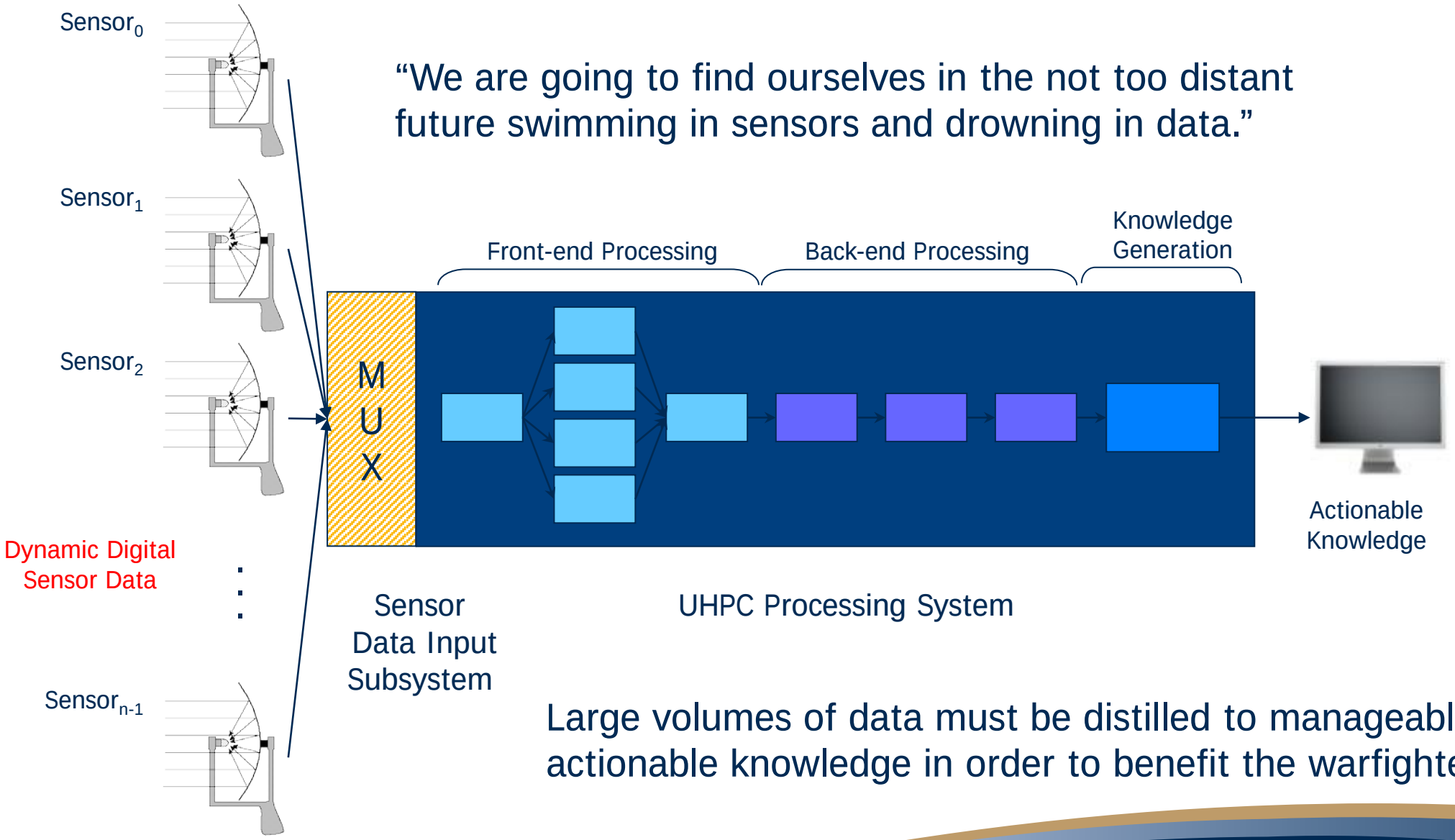
CP #1 – Streaming Sensor



"We are going to find ourselves in the not too distant future swimming in sensors and drowning in data."

Large volumes of data must be distilled to manageable, actionable knowledge in order to benefit the warfighter

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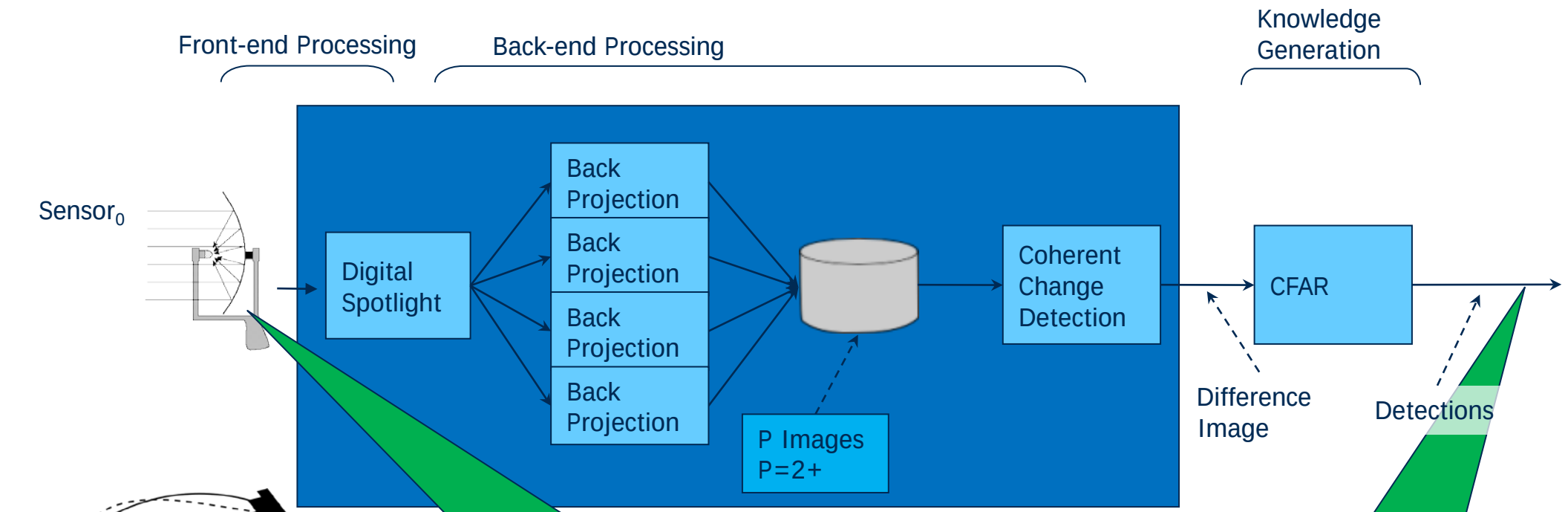
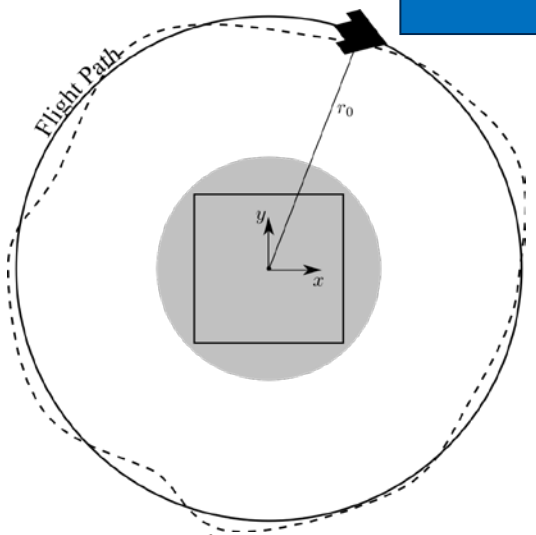
Overview - SSCP





Inputs:

- **Sensor collections**
  - For each of many pulses:
    - Sensor position
    - Measured returns at many time instances
- **Grid of image point locations**

Outputs:

Location of each detection

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Why Backprojection?

- **FFT-based reconstruction techniques exist**
  - Require either linear or circular collections
  - Only modest deviations can be compensated
  - Requires extra steps to get georeferenced imagery
  - Images only onto planar surface
- **Procedure**
  - ~~Attempt to fly a perfectly straight line~~
  - ~~Compensate for unwanted motion~~
  - Form image using ~~Fourier-based method~~ backpropagation
  - ~~Register and interpolate image onto map coordinates~~
- **Flexibility**
  - Can image directly onto map coordinates without postprocessing
- **Expanded operating envelope**
  - Can image in adverse environmental conditions during maneuvers

Digital Spotlight

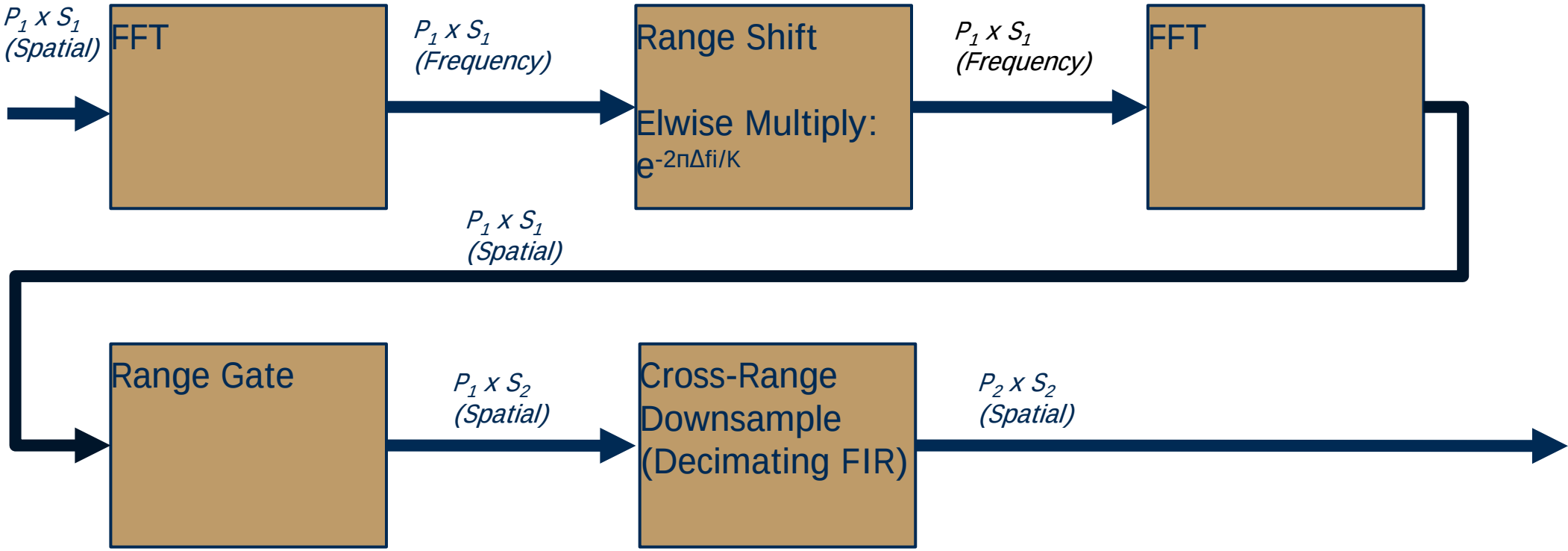
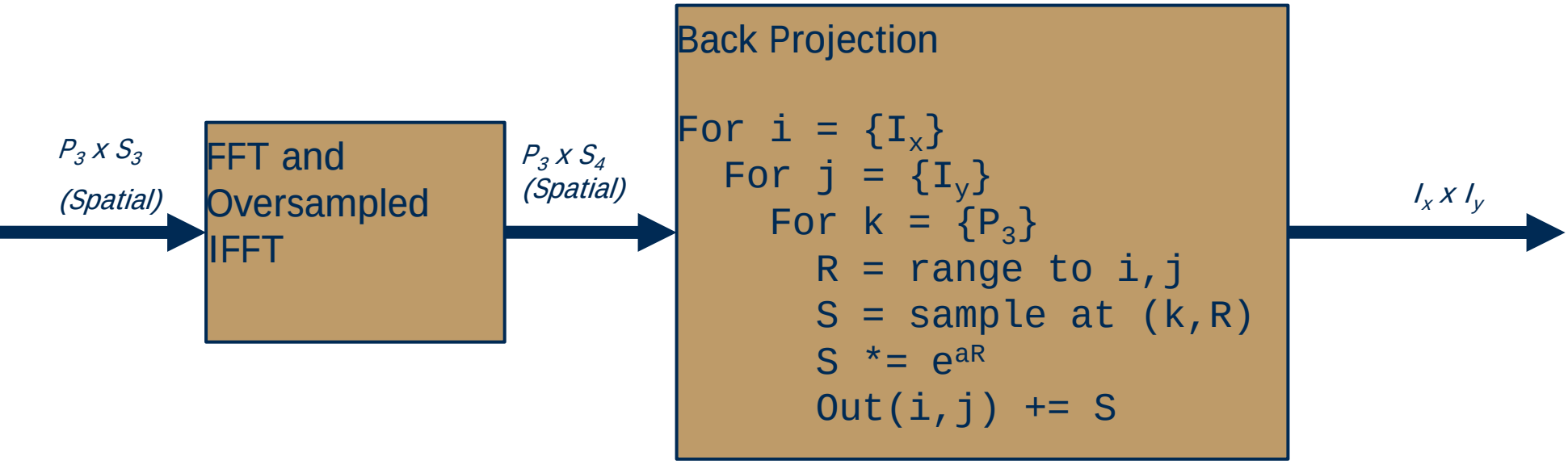
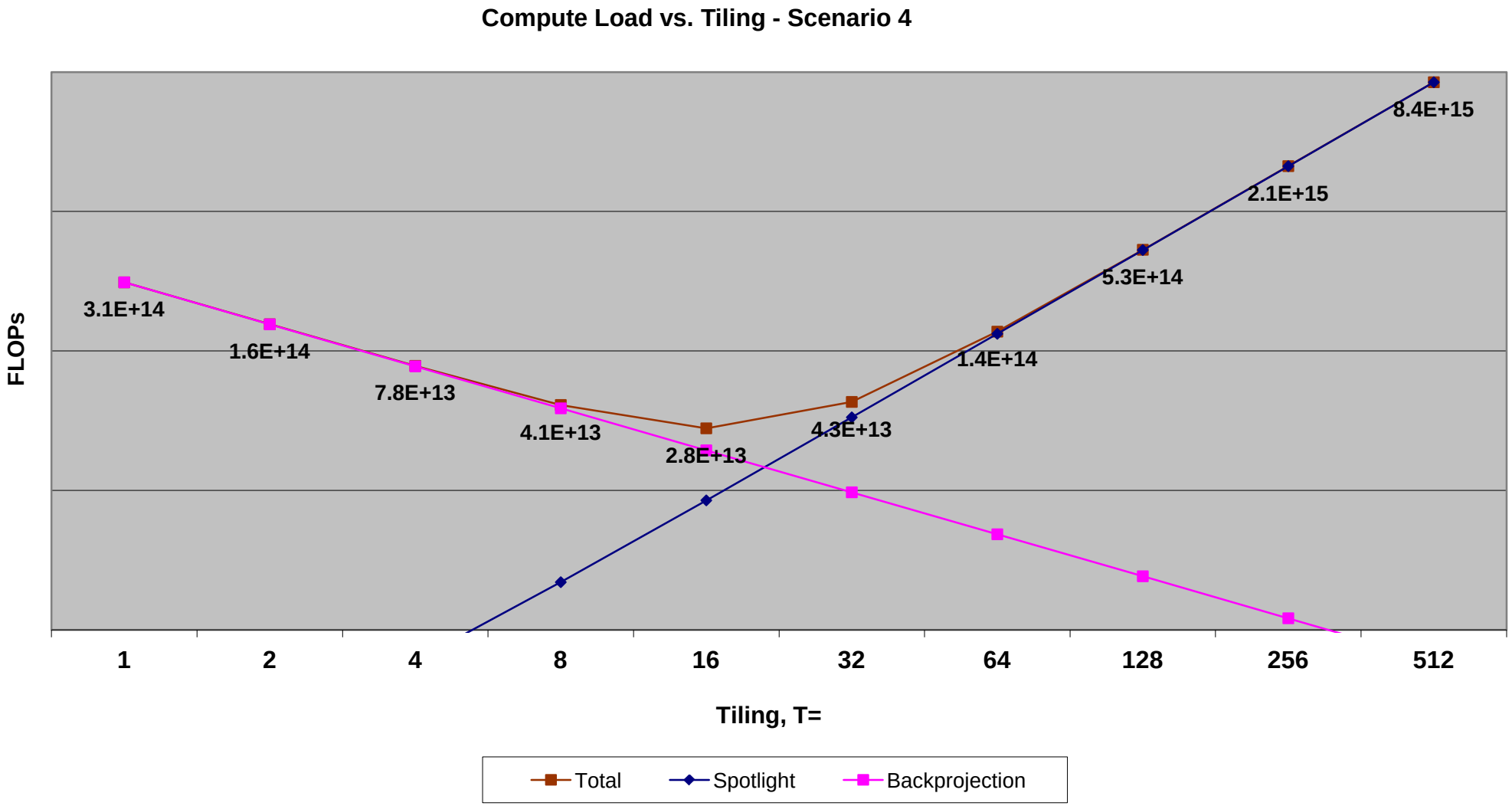


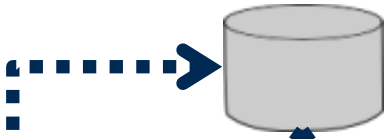
Image Formation



Digital Spotlight Loading Impact



CCD(1) - Affine Registration



$$X_o = Z_1 + Z_2X_i + Z_3Y_i + Z_4X_i^2 + Z_5Y_i^2 + Z_6X_iY_i$$

2D Correlate x N_c

$(2S_c\text{-}1x2S_c\text{-}1)$ 2D FFT
Elwise mult
2D IFFT
R_cxR_c Max Mag

Control Points: N_cx4
(Locations, Offsets)

Find Global Affine Transform

AZ = b

Solve for Z

A: N_cx6
[1 x y x^2 x^2 xy]
(x,y = Control point locations)
b: N_cx2
(each row =final x,y position)

Warp & Sample

C = AZ
Bilinear sample @ C

Z = Warp Weights: 6x2

C: Warped loc
A(i,:) = [1 x y y x^2 y^2 xy]
i = 1..M^2
One row per pixel
Z: 6x2

- R_c = ~2*% x M
  - Round up to NPOT
- $S_c = R_c$ x r
- S_{cf} = 16* x r
- r = 4*
- N_c = ceil$(M/R_c)^2$
- *Heuristics

M x M Complex Image

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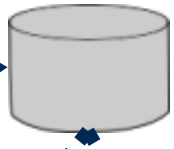
CCD(2) – Thin Spline Registration



M x M Complex Single Precision Image

2D Correlate x N_f

$(2S_{cf}\text{-}1 \times 2S_{cf}\text{-}1)$ 2D FFT
Elwise mult
2D IFFT
$R_f \times R_f$ Max Mag

Control Points: N_fx4 (Locations, Offsets)

Form L

$L = [K\ P;\ P'\ O]$

$K(I,j) = U(|X_i\text{-}X_j|)$
$U(n) = n^2 \ln(n)$
$P(i,:) = [1\ x_i\ y_i]$
$O = 0$
X_k:Ctrl Pt. Locs

- R_f = $2^{\text{ceil}(\log_2(R_c)/2)}$
- $S_{cf} = R_f \times 4$*
- N_f = ceil(M/D_f)2
- D_f = 200* (easy) ~1000* (hard)
- R_n = 5* (~1.5m)

*Heuristic

L: $(N_f+3)\times(N_f+3)$
Y: $(N_f+3)\times 2$

Find Weights

$LW = Y$

Each row of Y: control point + offset

Rows N_f+1 -> N_f+3 are zeroes

Solve for W

W = Warp Weights: $(N_f+3) \times 2$

Warp & Sample

$\Delta X_{x,y} = W_{Nf} + W_{Nf-1}x + W_{Nf-2}y + \Sigma W_i U(|P_i\text{-}(x,y)|)$

P_i: location of i*th* control point

Bilinear sample @ $X_{x,y}$

X = pixel location

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CCD(3) – Coherence / CFAR

- **Coherence**

  For each pixel: N_{cor}xN_{cor} 2D neighborhood correlation between current frame and reference frame

- **Constant False Alarm Rate (CFAR):**

  For each pixel, calculate whether this pixel's value is lower than T_{cfar}% of pixels in N_{cfar}xN_{cfar} neighborhood. If so, emit detection

CP #1 – Scenario Parameters

Scenario	1	2	3	4
Ground Area (square edge size, m)	609.6	1086	2438	8690
Image Size (edge size, pixels)	4000	7127	16000	57018
Pulses per Image	4800	12095	19200	96763
Samples per Pulse	4000	10079	16000	80636
Pulses per Second	1084	497		2809
Throughput (images per second)	1			
Affine registration control points	3629	14,513	58050	928799
Thin-spline registration control points	100	100	200	200
CCD neighborhood size	5x5			
CFAR neighborhood size	15x15			

CP #1 – Scenario Loading

Scenario		1	2	3	4
Floating Point Operations	Image Formation	23.2×10^9	149×10^9	942×10^9	28.0×10^{12}
	Affine Registration	1.11×10^9	4.45×10^9	17.8×10^9	160×10^9
	Thin-spline registration	25.8×10^9	103×10^9	819×10^9	13.1×10^{12}
	Coherent Change Detection	79.4×10^9	317×10^9	1.27×10^{12}	20.3×10^{12}
	CFAR Detection	715×10^6	2.86×10^9	11.4×10^9	182×10^9
Total FLOPS		130×10^9	577×10^9	3.06×10^{12}	**61.8×10^{12}**
Input bandwidth (bps)		80.0×10^6	320×10^6	1.7×10^9	14.5×10^9
Input footprint (Bytes per Image)		244×10^6	975×10^6	3.9×10^9	**62.4×10^9**

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SSCP Status

- Reference implementation completed & available to UHPC participants
  - Includes challenge problem & data generator
- Accelerated / Parallel implementations under development
- Investigating addition of EO/IR & Fusion
- Adjustments to registration process under investigation
- Adjustments to load-influencing parameters under consideration