Making Sense of It All

New Sensor Signal Processor Paradigms: When One Pass Isn’t Enough

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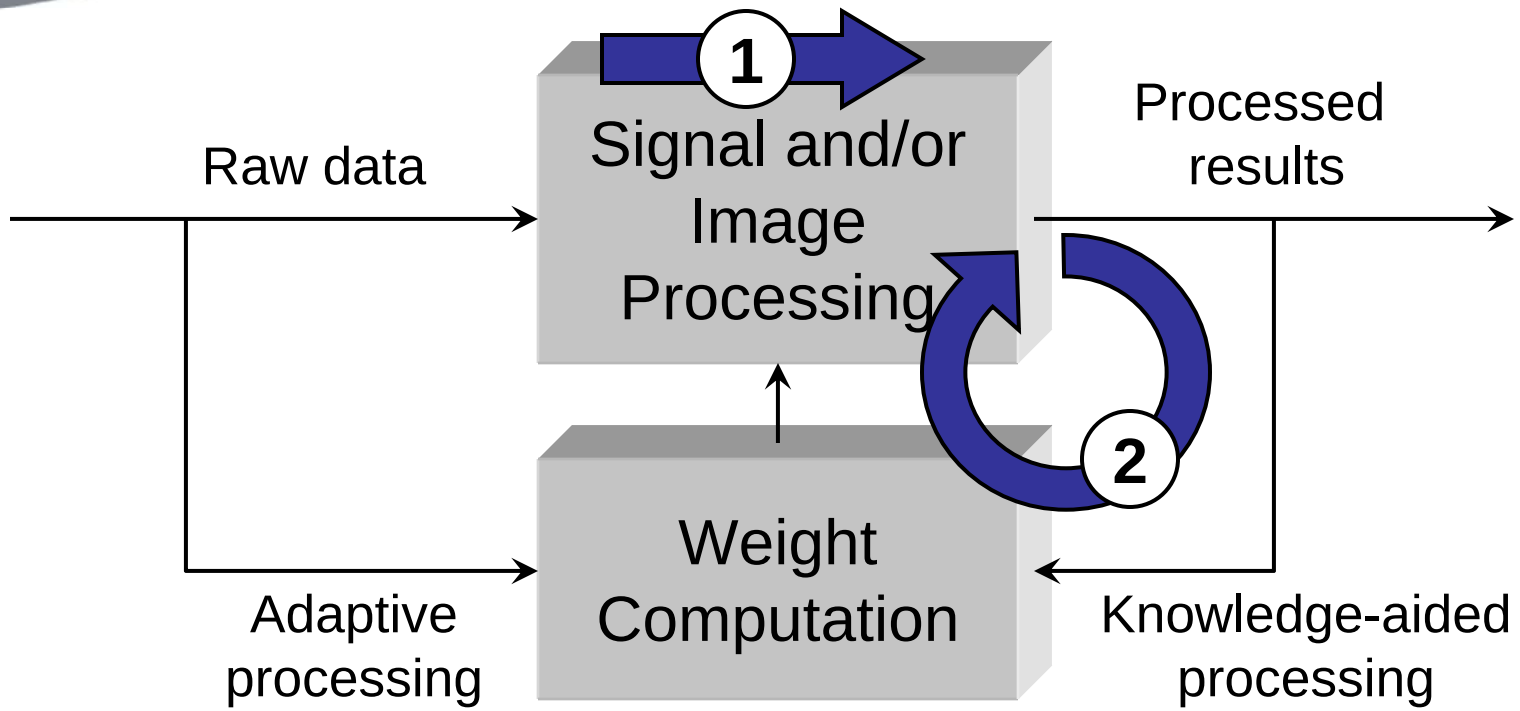
Outline

- Simplified evolution of signal processing
  - Stream processing vs. multi-hypothesis processing
- Multi-hypothesis example: model-based processing
  - DARPA VisiBuilding & Multipath Exploitation Radar Programs
- Impact on embedded computing architectures
- Conclusions

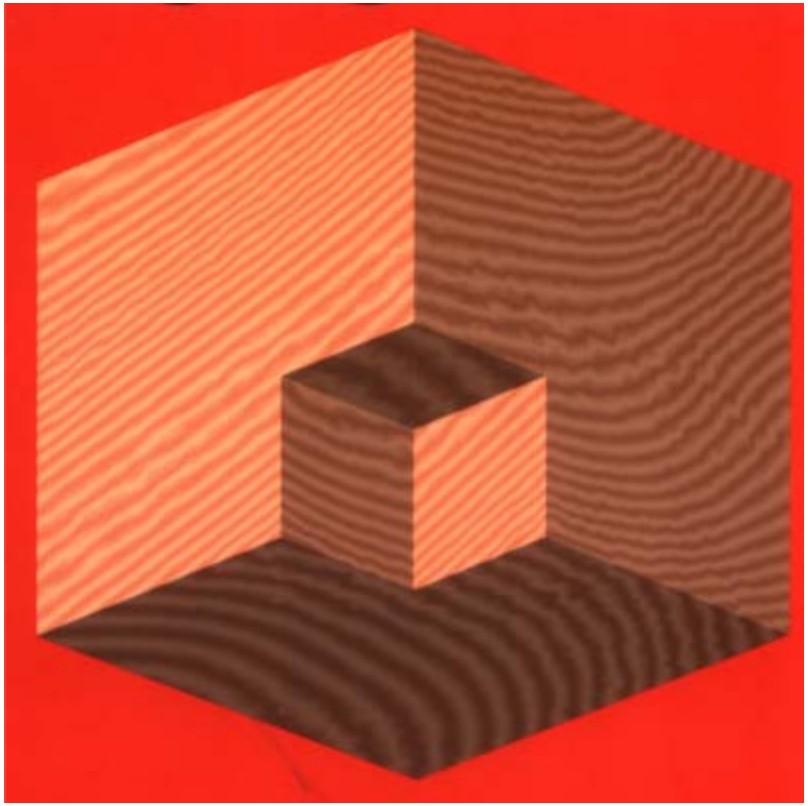
Simplistic Evolution of Signal Processing



1. Filtering
2. Adaptive processing
3. **Knowledge-aided processing**

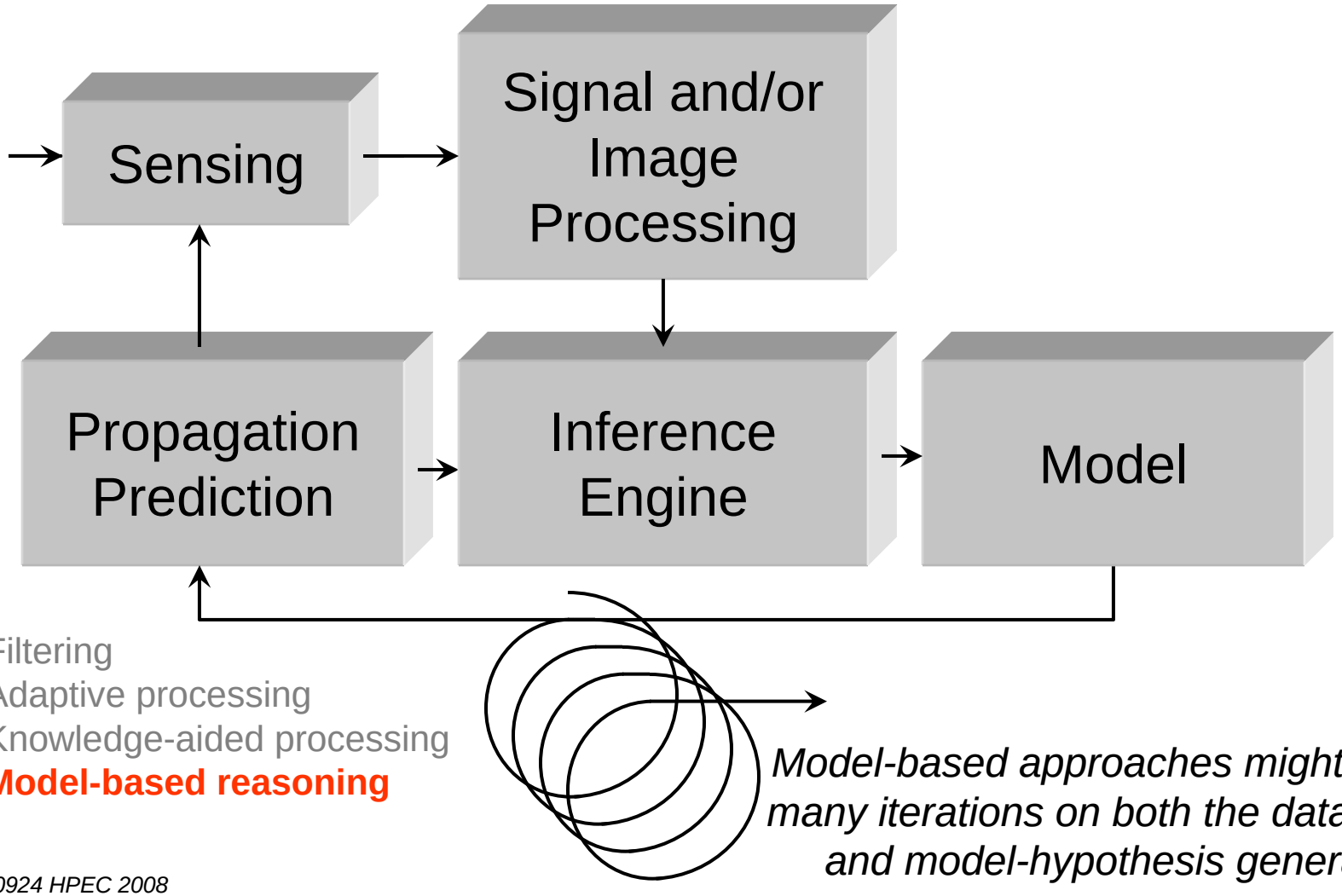
Stream signal processing can be impeded by smarter use of processed data

Digression: Model Interpretation Affects How You Process Data



"Seeing Double" , J. Richard Block (Routledge, 2002)

Model-Based Signal Processing



1. Filtering
2. Adaptive processing
3. Knowledge-aided processing
4. **Model-based reasoning**

Model-based approaches might require many iterations on both the data stream and model-hypothesis generation

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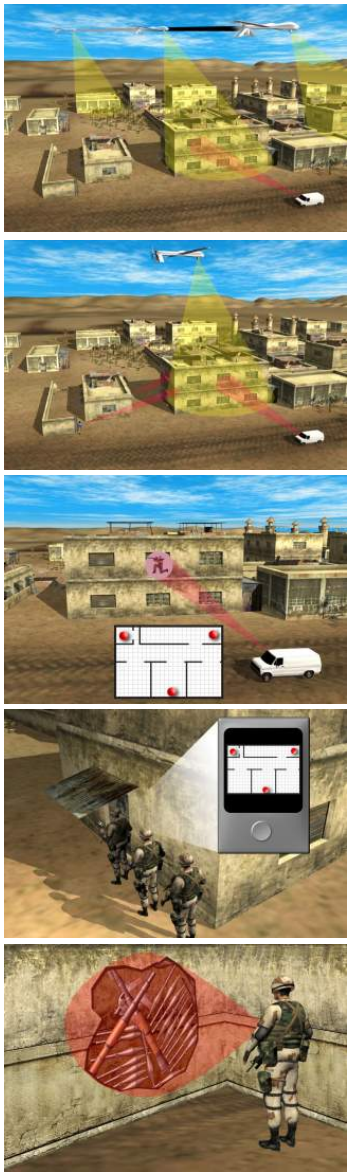
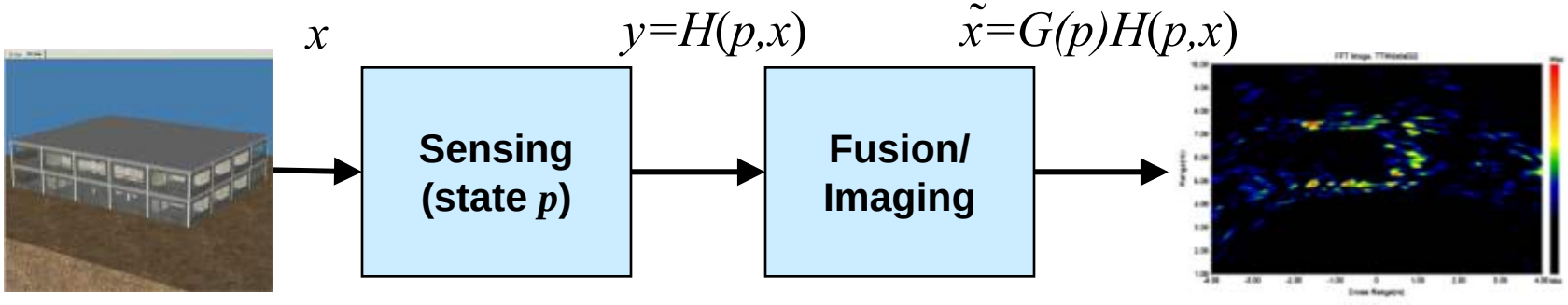
VisiBuilding Program

- Objective: Develop innovative sensing and exploitation architectures to see inside buildings
  - Find personnel inside of buildings
  - Provide building layouts (walls, rooms, stairs, doorways)
  - Identify weapons caches, shielded rooms, etc.
- Ideal approaches should:
  - Provide actionable information (e.g., model-based, not radar blurs)
  - Support range of CONOPS
  - Provide robustness to urban environment



SAR-Based Building Imaging



- Current imaging assumes that sensing is a separable function of sensor position p and structure x
- Algorithms imply that inverse function can be approximated:

$$x = \{G(p)H(p,x)\} = H^{-1}(p)H(p,x) \approx x$$

- Fatal flaws:
  - $H(p,x)$ is a highly nonlinear mapping with no direct inversion
  - Approach cannot easily exploit known constraints on x

Open-loop imaging doomed to fail in complicated environments!

VisiBuilding Approach

x

$y=H(p,x)$

Sensing (state p)

Fusion

$GH(p,x)$

δp

$\tilde{x}$

$G\tilde{H}(p,\tilde{x})$

Propagation Prediction

Imaging/ Inferencing

δx

3-D Building Model

$\tilde{x}$

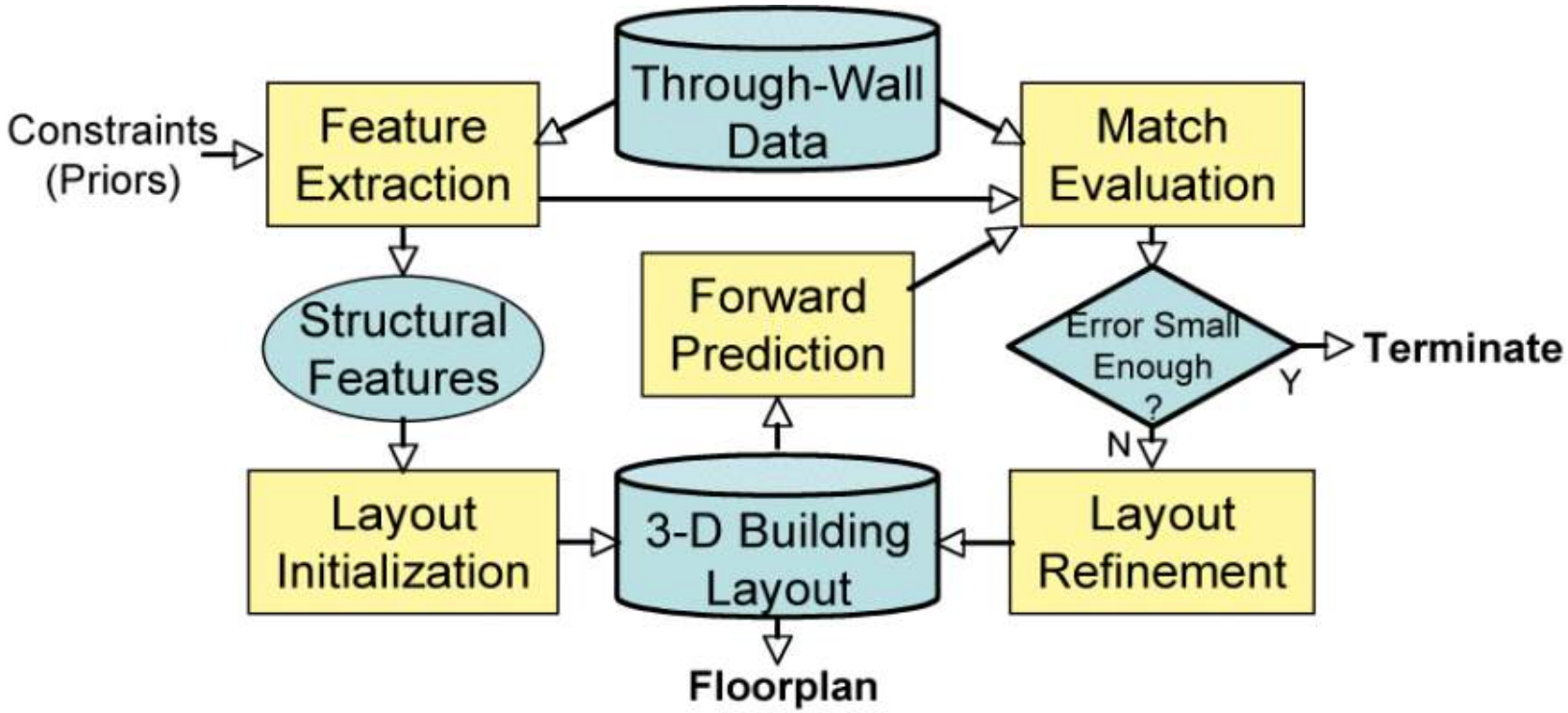
Building constraints; material properties

Bootstrap with imaging, then $\min_{p,\tilde{x}} J\{GH(p,x)\text{-}G\tilde{H}(p,\tilde{x})\}$

General approach:

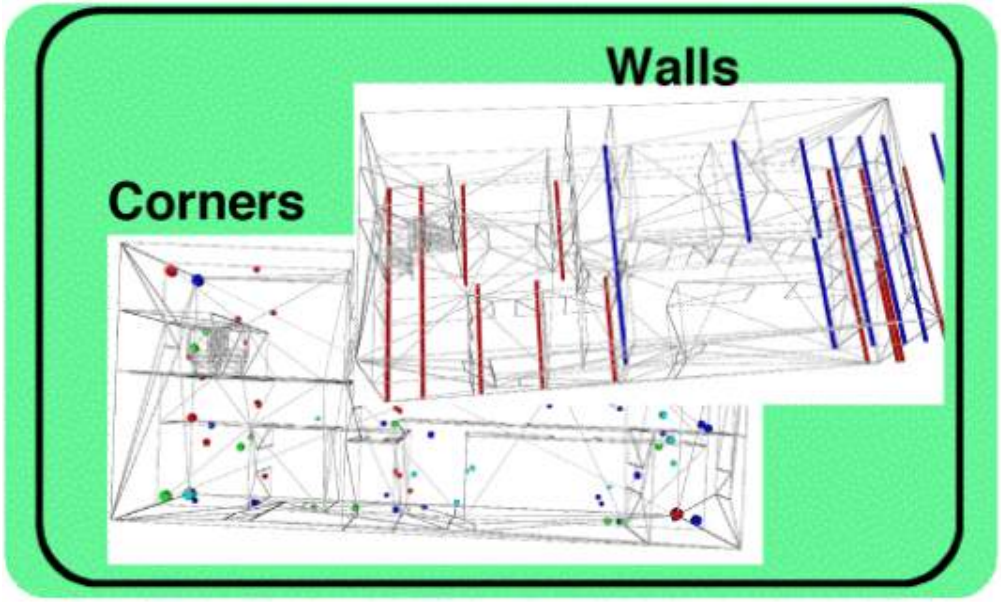
1. Use baseline p_0 to maximize initial information
2. Determine dominant features
3. Update model with new features
4. (optional) Modify sensor state p
5. Predict output due to model and compare with data
6. Stop if converged; otherwise, Iterate to step 2

OVERALL RECONSTRUCTION APPROACH

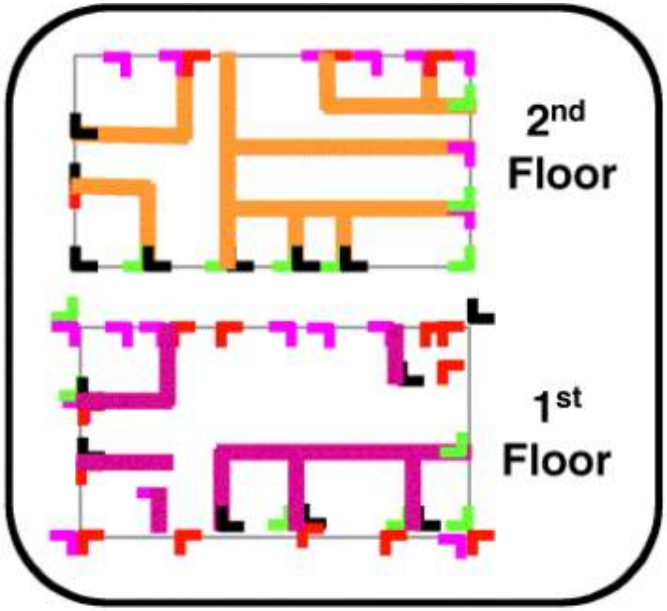


Model-based reasoning requires forward prediction and iterative refinements of the model

LAYOUT INITIALIZATION

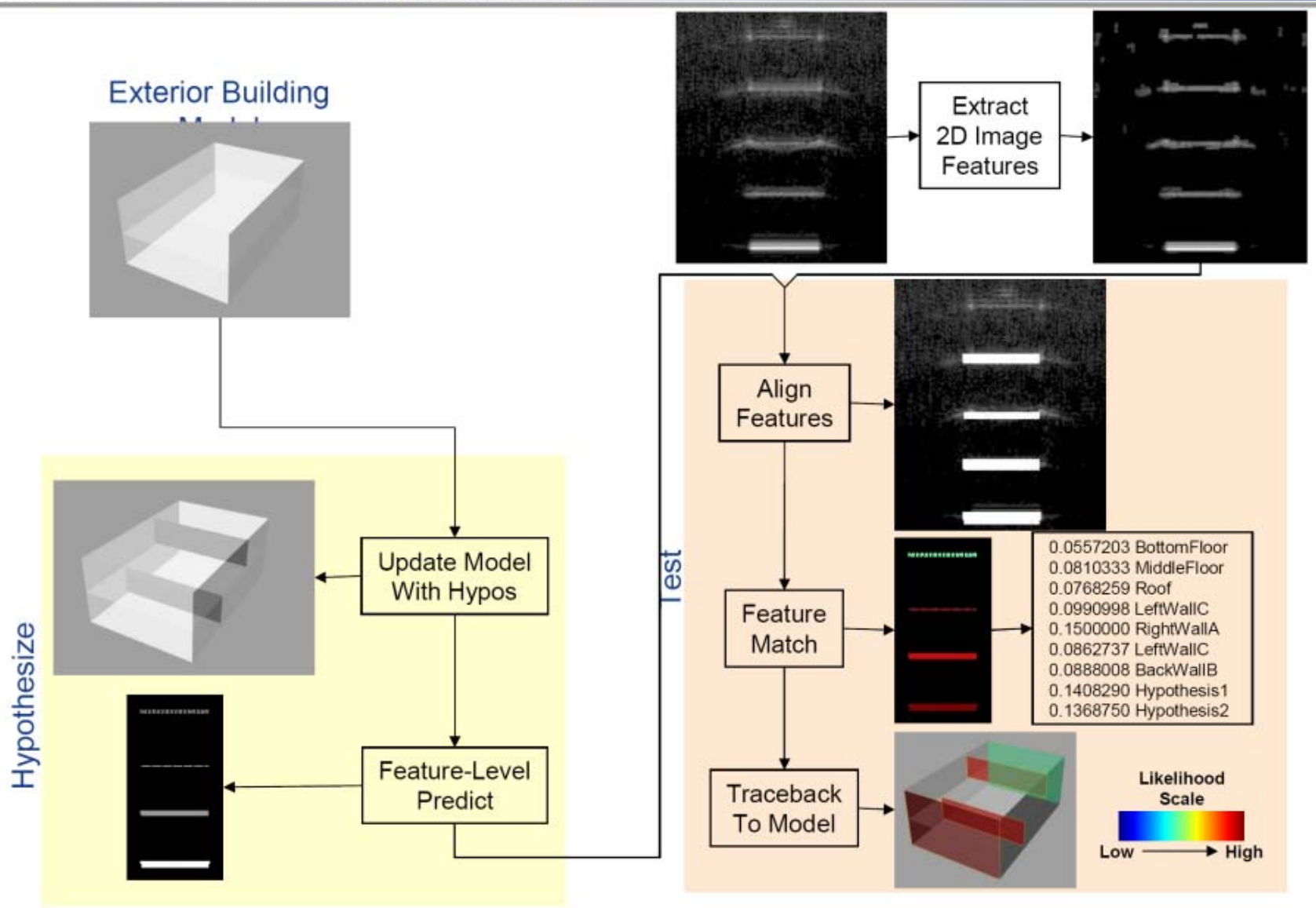


a) Extracted Features

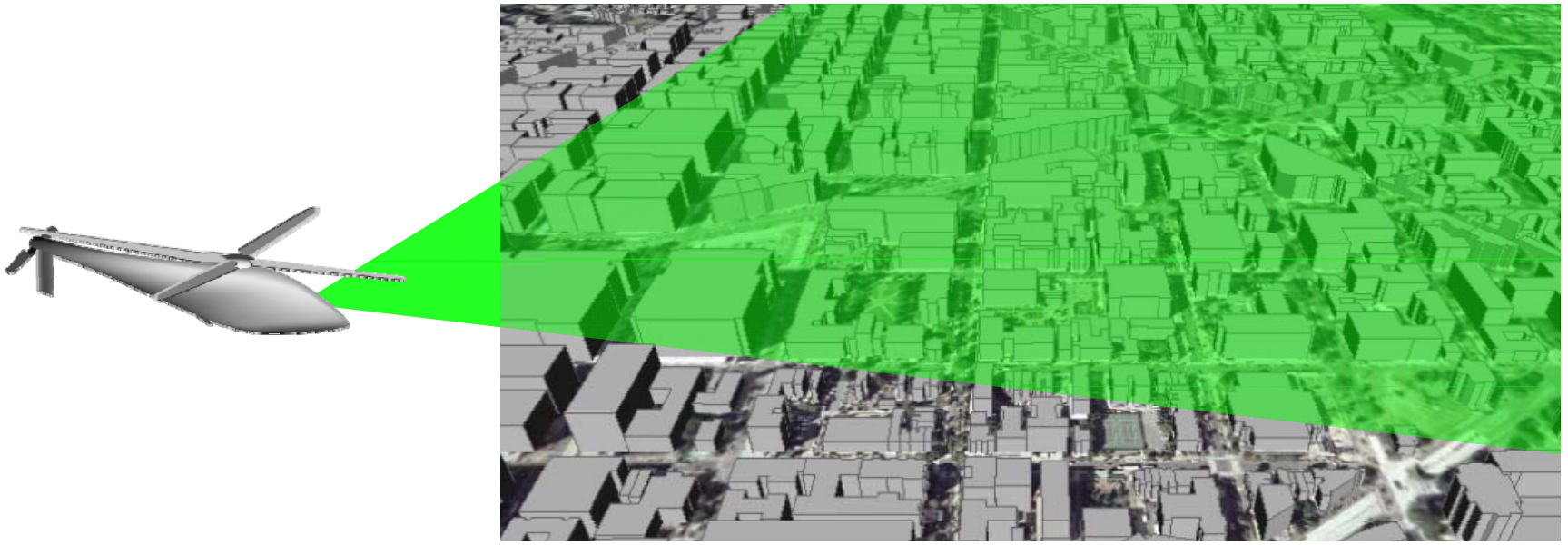


b) Hypothesized Layouts

Hypothesize-and-Test, Illustrated



Multipath Exploitation Radar for Urban Tracking



- Multipath Exploitation Radar can provide *persistent* wide area tracking of vehicles in a metropolitan area like Baghdad using only three UAVs at 15 kft altitude
  - Track high value targets through dense city streets without direct line-of-sight
  - Provide long-term track history of all targets for post-event forensics
- Enabling technology uses specular multipath off buildings to see into urban shadows and canyons
  - Provides six-fold increase in sensor coverage area over physical line-of-sight limit

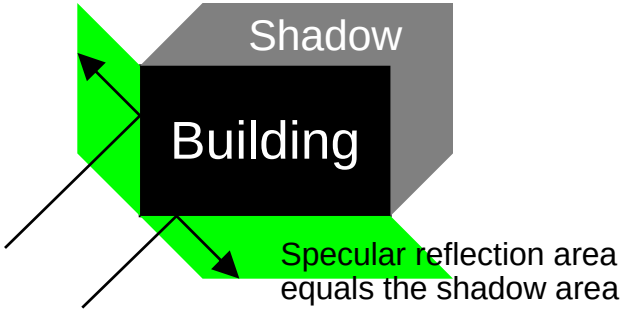
Multipath Exploitation Radar can cover entire Baghdad metropolitan area with three multipath exploiting airborne sensors!

Line of Sight vs. Multipath Coverage

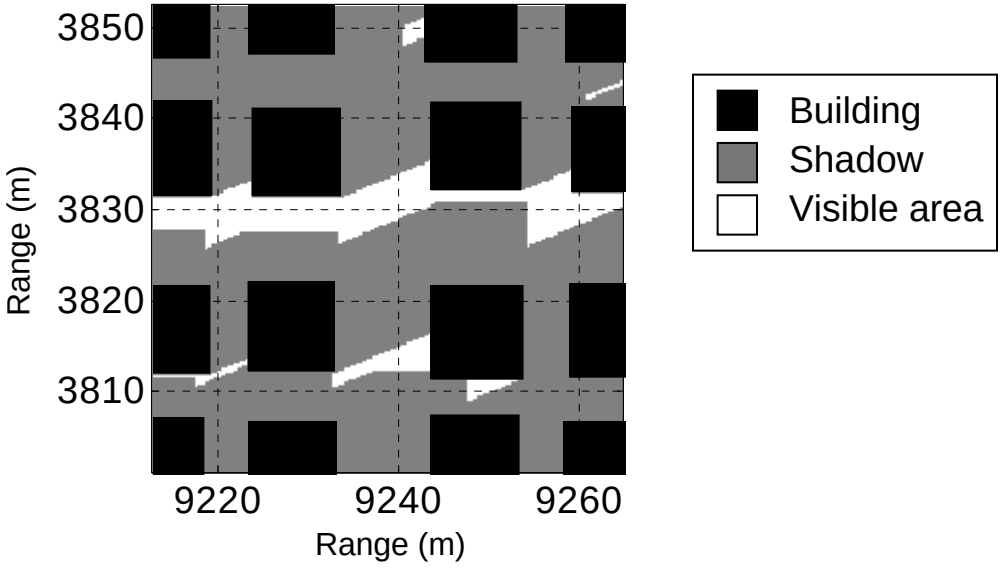
Concept

Example: Surveillance of a typical urban scene (two to four story buildings) as seen by 15 kft UAV

- Top down view of typical city block shown
- Line-of-sight shadows dramatically reduce visibility of roads between buildings
- Multipath fills in the shadows

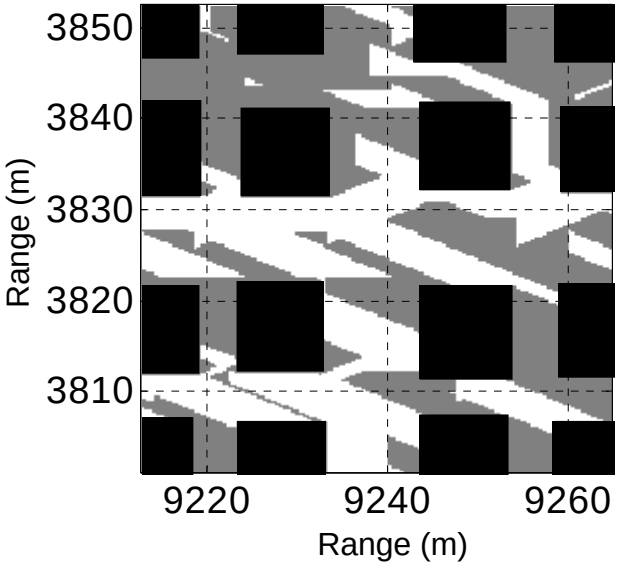


Line of Sight visibility, 15% area coverage



Urban shadows are fatal for line-of-sight systems

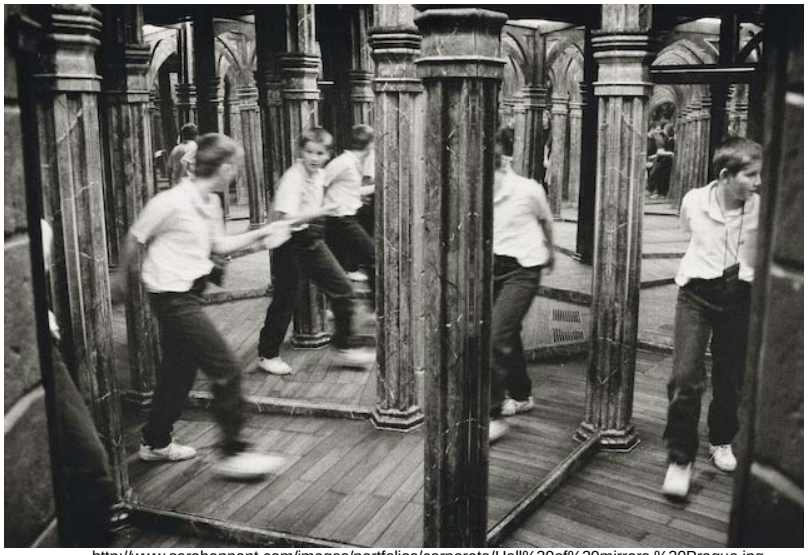
Multipath and LOS, 47% area coverage



Specular reflections from buildings fill urban shadows and increase road visibility

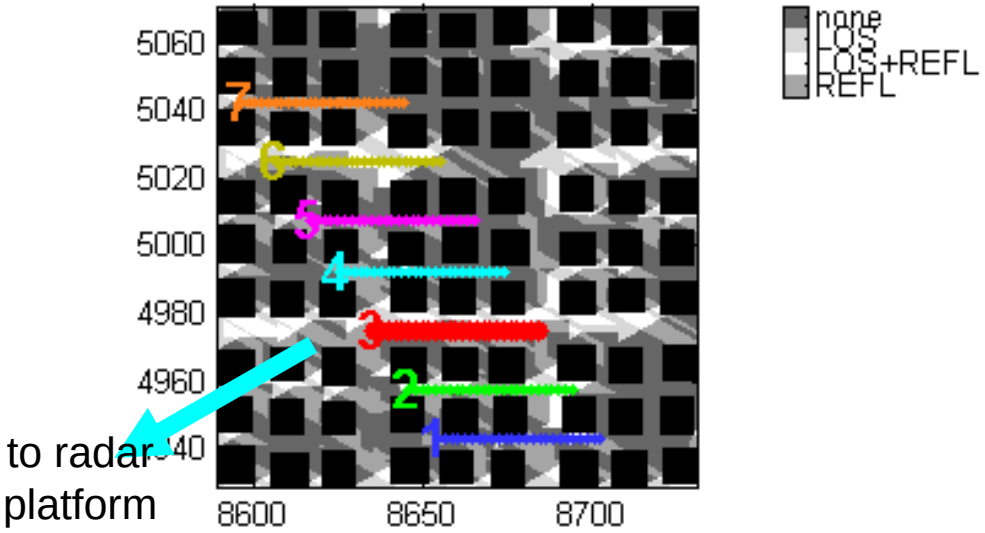
Specular reflection allows detection within urban canyons

Multipath Hypothesis Tracking: "RF Hall of Mirrors"



http://www.sarahannant.com/images/portfolios/corporate/Hall%20of%20mirrors,%20Prague.jpg

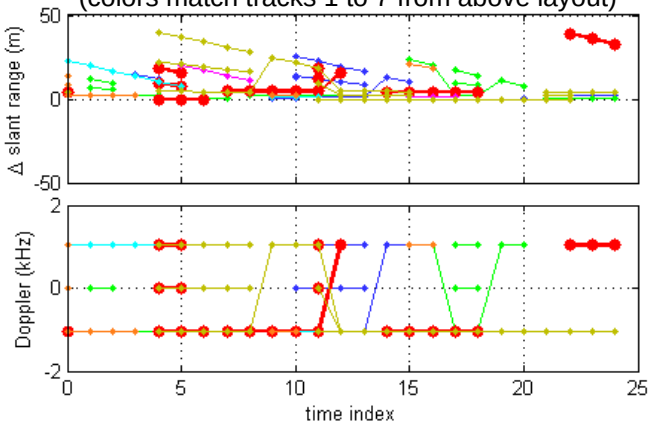
Target tracks overlaid on urban layout:



- Range-Doppler returns from multipath reflection structures are unique "fingerprints" for different tracks

Slant range and Doppler histories:

(colors match tracks 1 to 7 from above layout)



Multipath returns provide fingerprint identifiable to urban location

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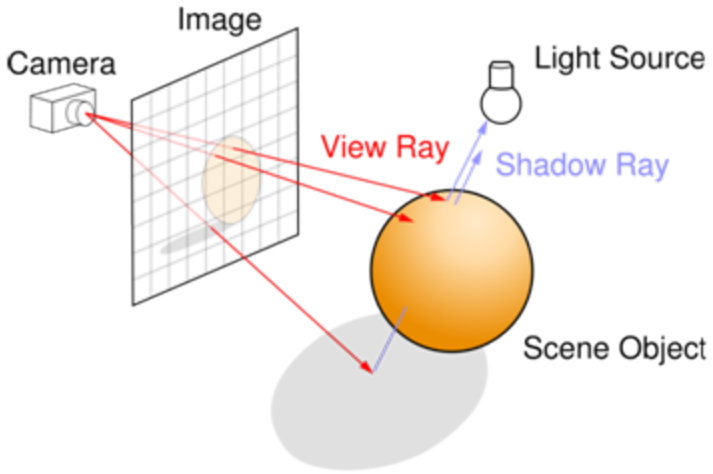
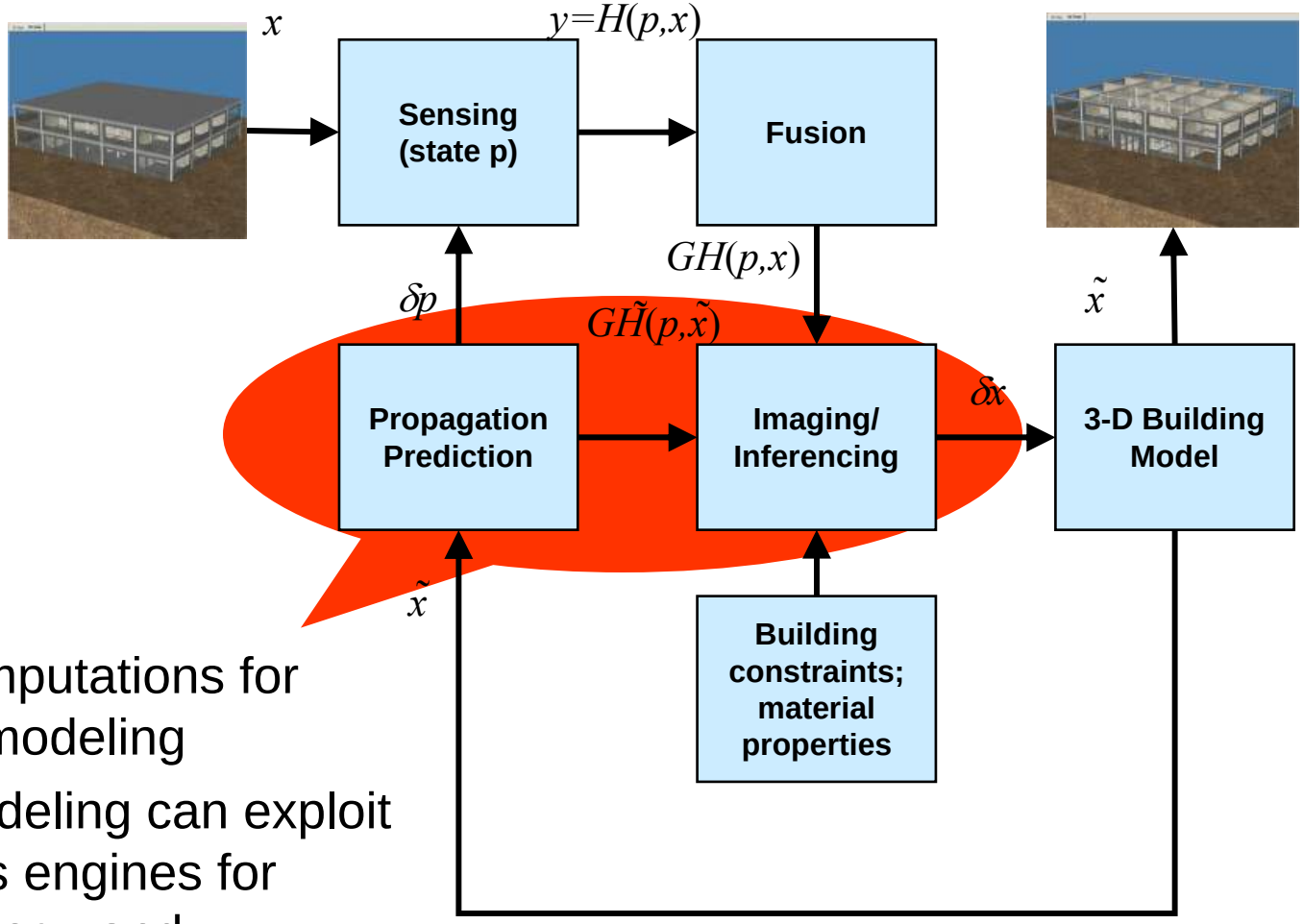
Impact on Embedded Computing Architectures

- Many future applications will not yield to conventional stream processing approaches
- Model-based approaches will require physics-based computation and inferencing ideally suited for dedicated co-processors (e.g., GPUs and FPGAs)



http://en.wikipedia.org/wiki/Ray_tracing_(graphics)

Physics-Based Architectures



- Teraflop computations for hypothesis modeling
- Physical modeling can exploit 3-D graphics engines for phenomenology and hypothesis testing

Summary

- Signal processing will migrate from stream signal processing approaches to physics-based multi-hypothesis processing
- Several DARPA programs (VisiBuilding and Multipath Exploitation Radar) are already pushing algorithm development in these areas
- Unique convergence with GPU processing technology is ideally suited for physics-based approaches