Selected Enhanced Fidelity AIM Methods

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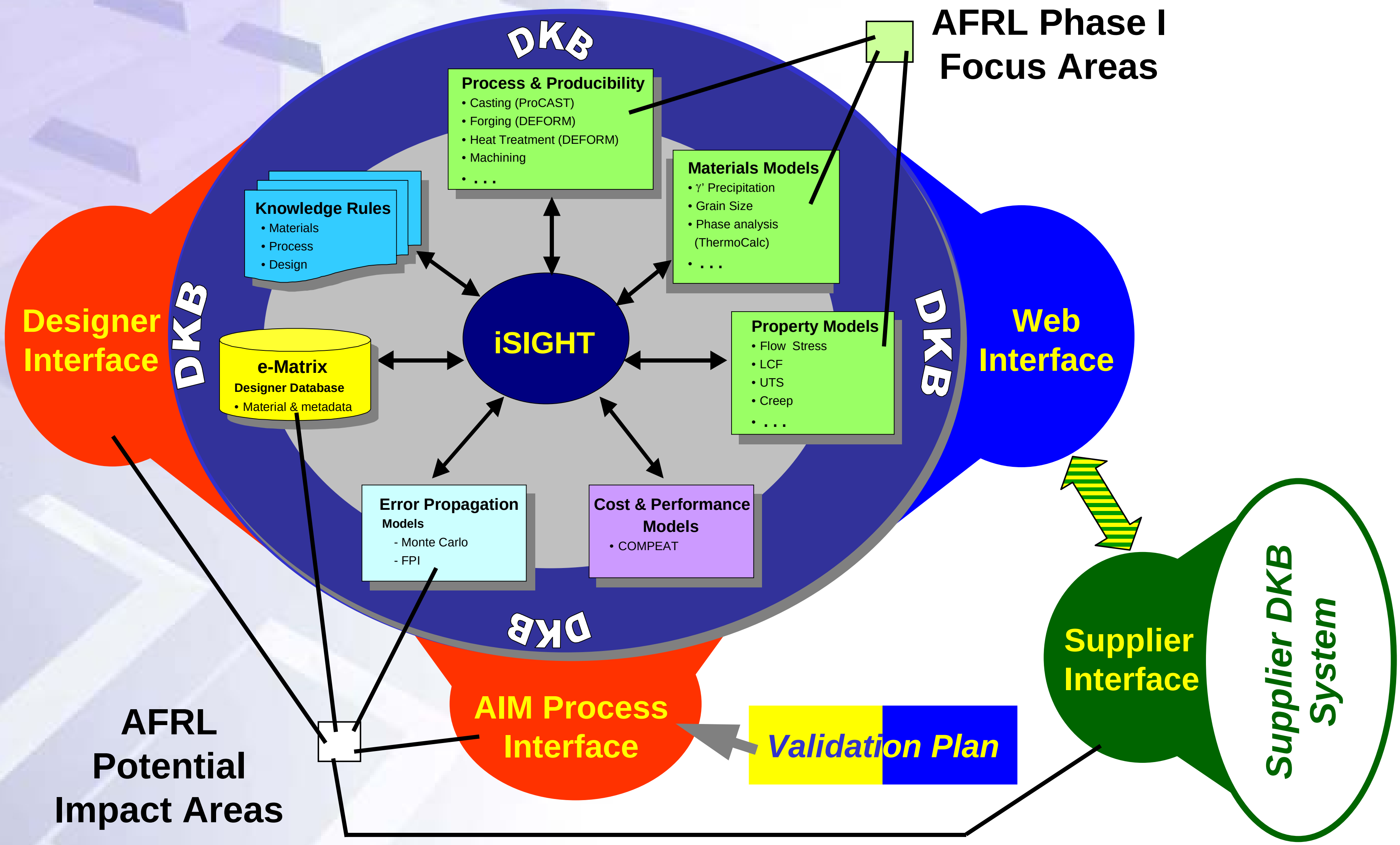
AIM System Architecture



Requirements flow from AIM architecture

What About Phase II & Beyond?

In general, demand is for methods to treat unknown (without database)

Numerical descriptions needed for scope & fidelity in performance prediction (property minima & fracture are locally dominated)

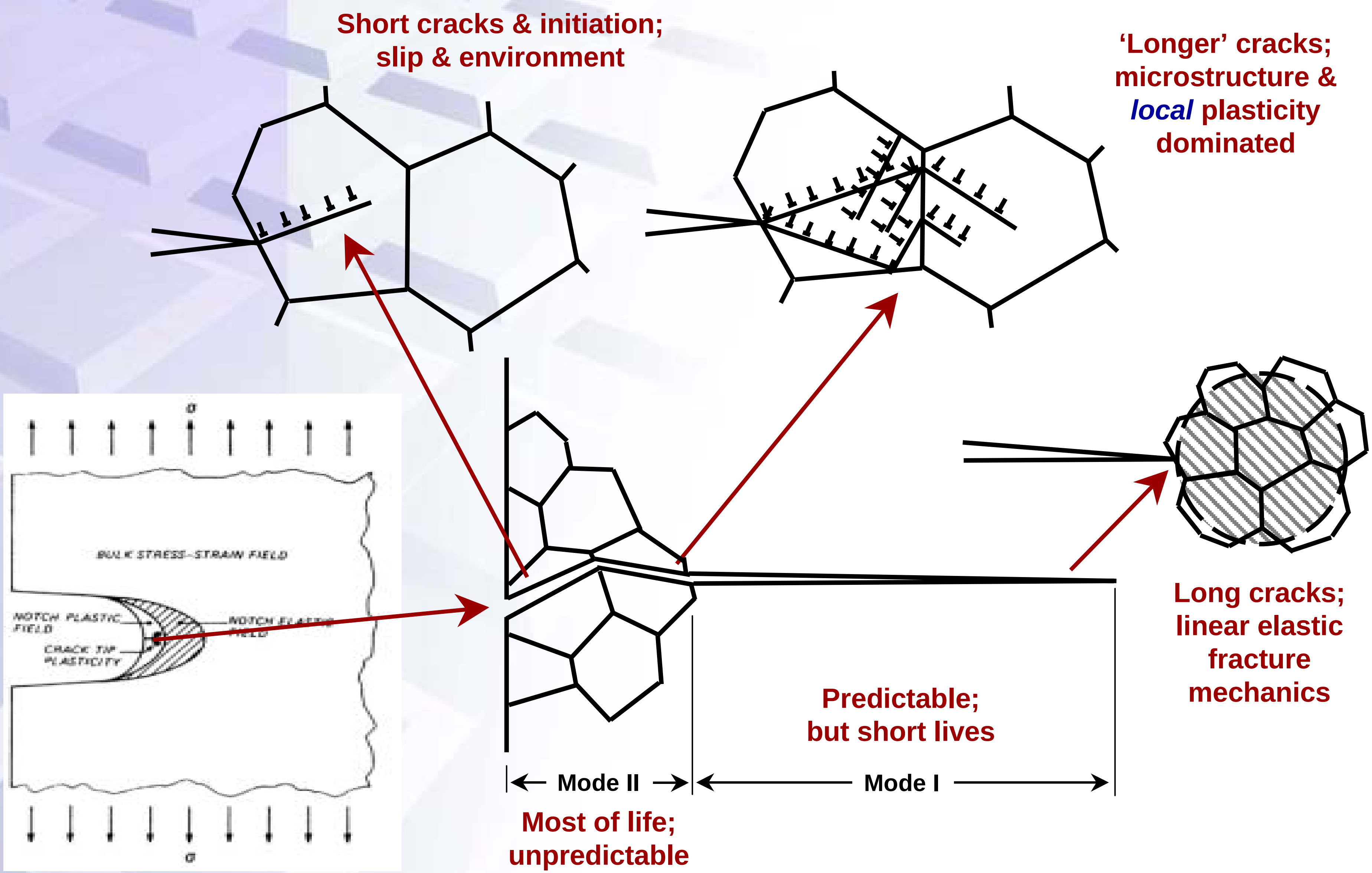
These require development and adaptation to system architecture

Thus AFRL Focus:

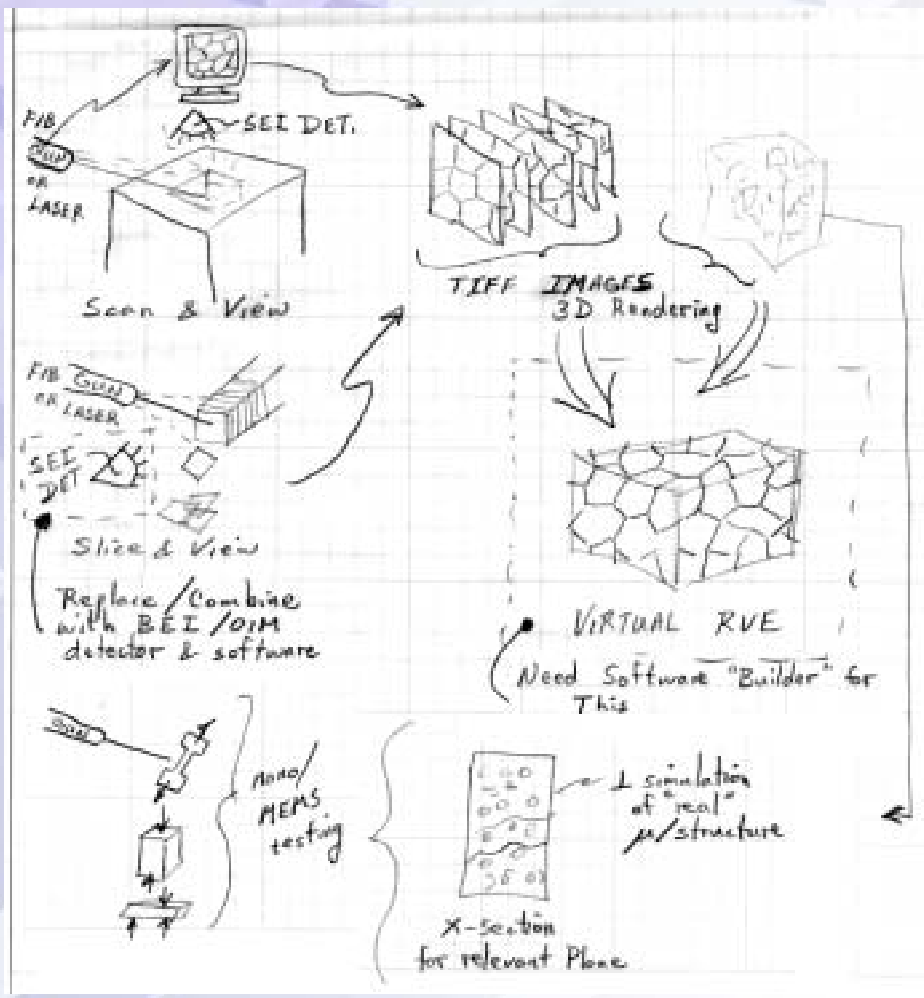
- Prediction, quantification & representations of structure evolution & kinetics
- Structure-sensitive numeric descriptions of properties
- Overlay of ‘homogenized’ or ‘fast-acting’ models, validation/tuning procedures, & interlace with design/architecture

Accelerated Insertion of Materials

Need for Microstructure-Based Plasticity



From Concepts to Realities



Last year's 'sketchy' concept

Briefings on Today's Progress

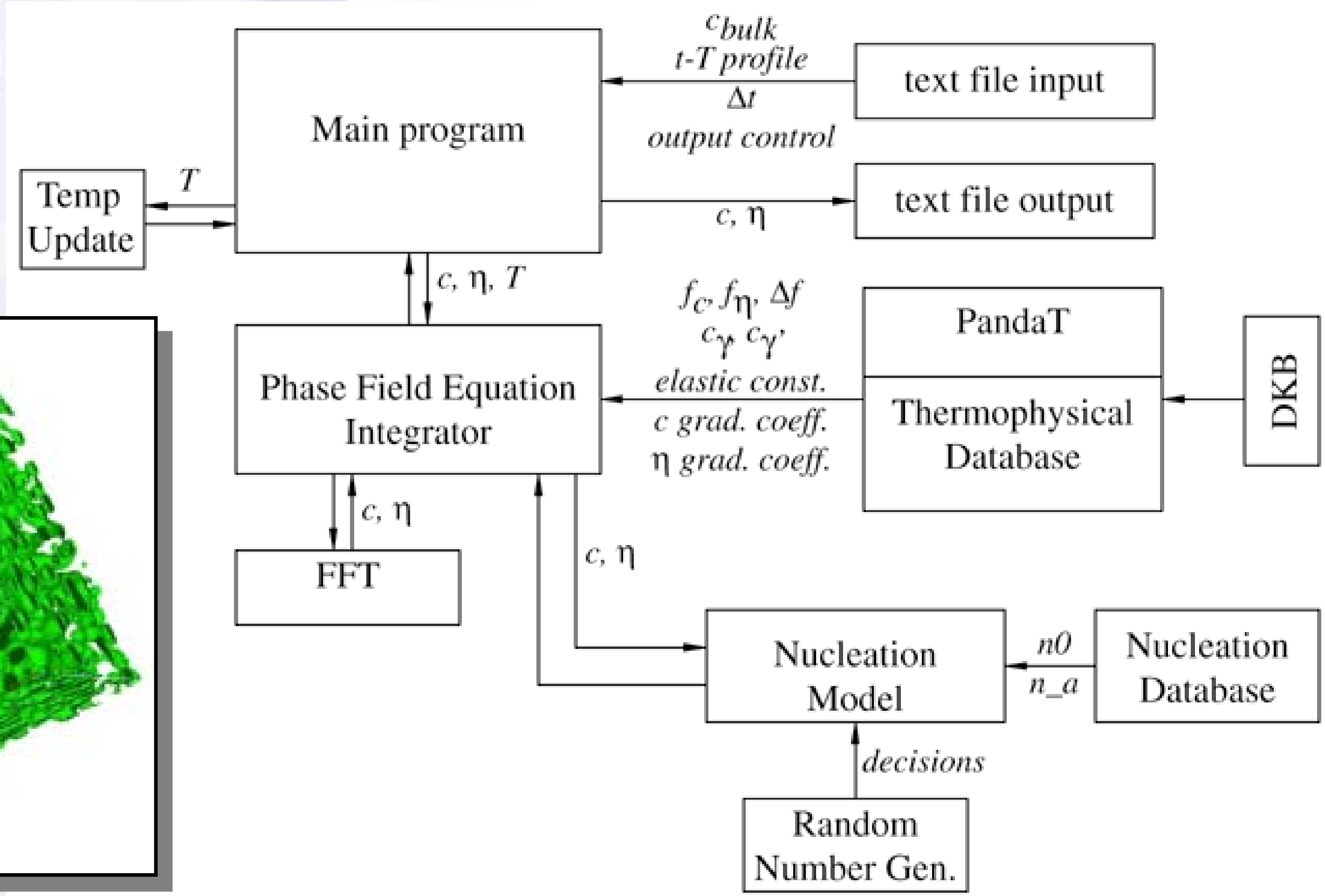
Phase Field (Simmons, 20min)

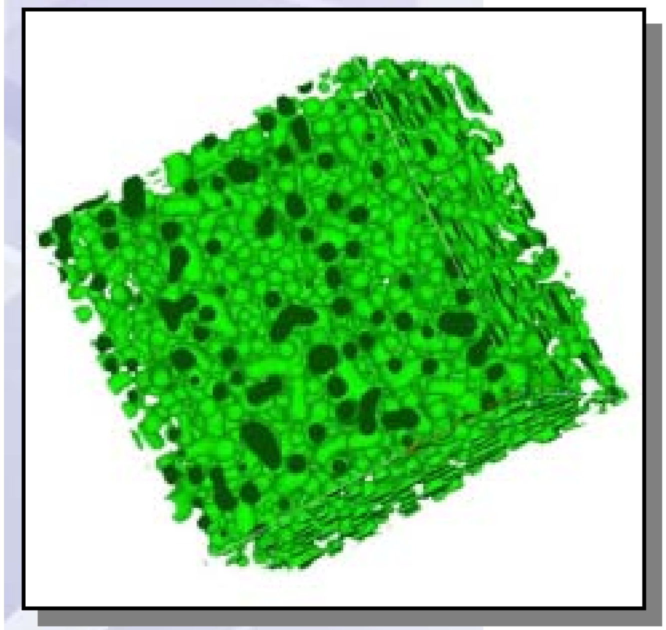
Plasticity Modeling (Parthasarathy, 20min)

Advanced Experimental Methods
- **3D Quantification (Uchic, 10min)**
- **Representation (Simmons, 15min)**
- **Micro- & Nano-scale Tests (Uchic, 15min)**

Broader View & Discussion (Dimiduk, All)

Architecture & Implementation of Phase Field Software





3D, Isothermal γ-γ' Coarsening

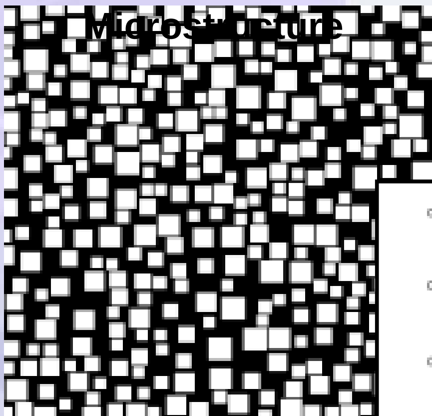
Clear framework identified…real dimensionality, thermodynamics evolving!

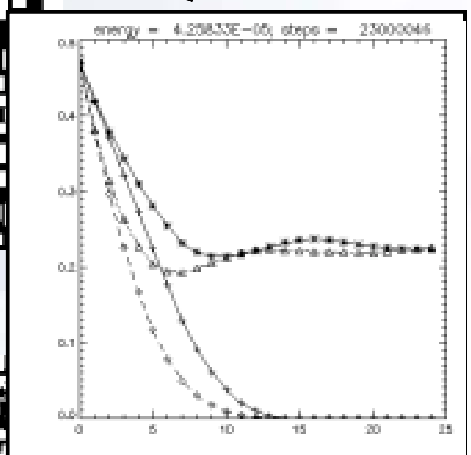
Simmons, Woodward, Wen, Menon, Shen & Wang, 2002

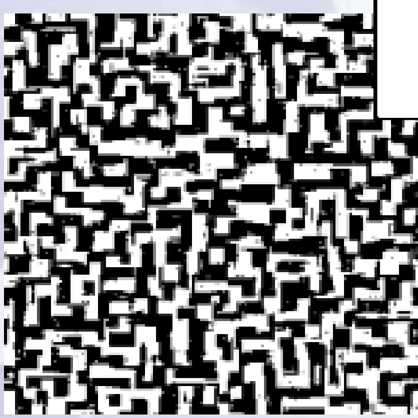
Microstructure Representations

2-Point & Lineal Path Functions

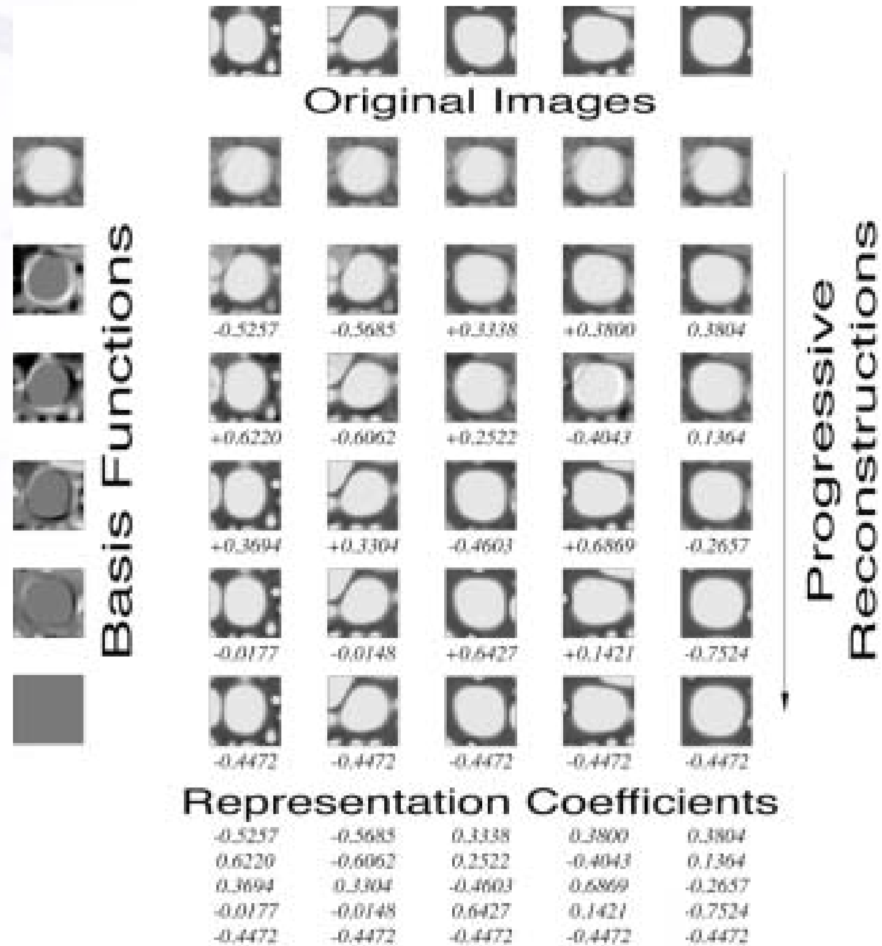
Idealized Microstructure







Monte Carlo Reconstructed Representative Microstructure



Principal Component Analysis (KLT)

Revolutionary longer-term approach to capture all information contained in microstructure

Beyond Analytical Strength Models

$$\sigma_y(C_i, T, \varepsilon, \dot{\varepsilon}, \ldots) =$$

Needs Development Within Atomistics

$$f_\gamma\left(\frac{T_o}{T}\right)\left(\sum_i \frac{dc}{\sqrt{dC_i}}\sqrt{C_i}\right) + Mf_t\left(\frac{\Gamma_{APB}}{b}\right)$$

Obtain by Dislocation Kinetics Simulation

$$M\frac{4}{\pi^{1.5}}\cdot\frac{T_L}{bd_s}\sqrt{f(1-f_p)}\sqrt{\left(\frac{\pi d_s \Gamma_{APB}}{2T_L}-1\right)}$$

strong coupling

$$+$$

$$M\left[\left(\frac{\Gamma_{APB}}{2b}\right)^{1.5}\sqrt{\frac{2bd_s f(1-f_p)}{T_L}}\cdot\frac{4}{\pi^{1.5}}-\frac{\Gamma_{APB} f(1-f_p)}{2b}\right]$$

weak coupling

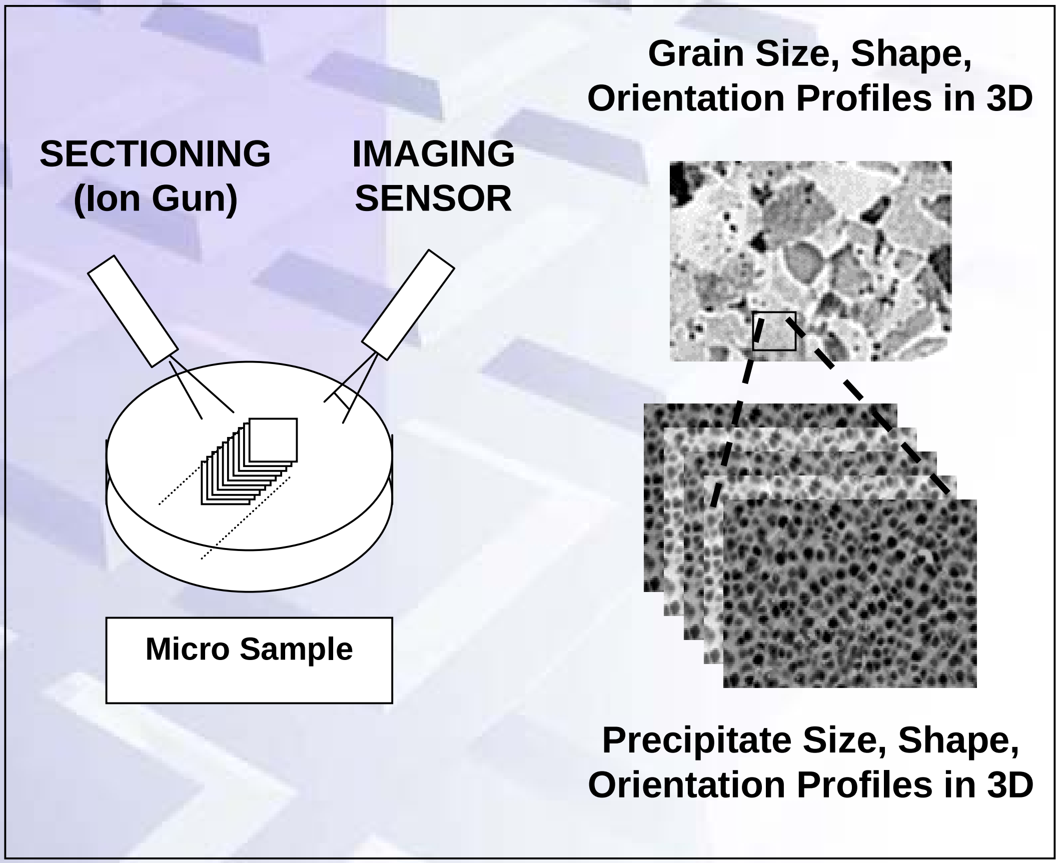
see Reppich

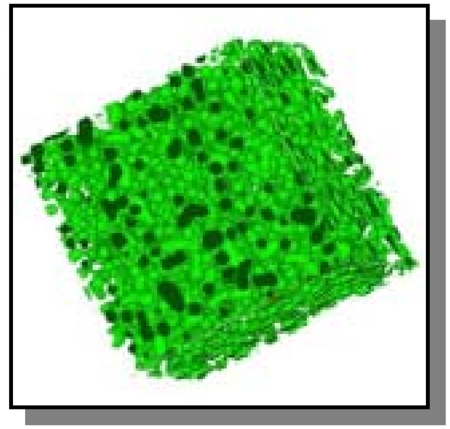
Obtain by FEM Simulation of Grain Distribution Effects

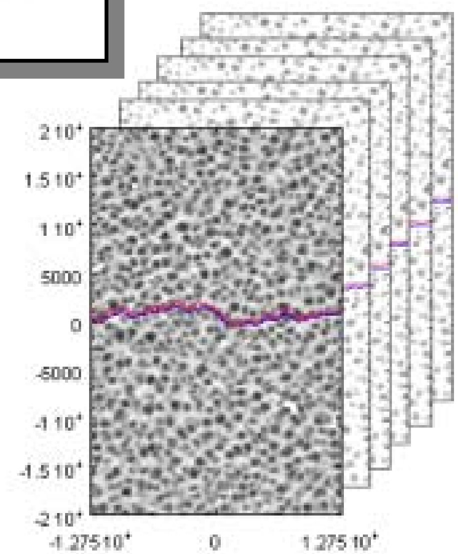
$$+\ f_p\left[\sigma(T)_{Ni_3Al}+\sum_i\left(\frac{dc}{dC_i}C_i\right)\right] + f_p k_y^{\gamma'}\frac{1}{\sqrt{d_{\gamma'}}} + (1-f_p)k_y^{\gamma}\frac{1}{\sqrt{d_\gamma}}$$

Numeric methods need and interface to AIM system

Unknown New Materials







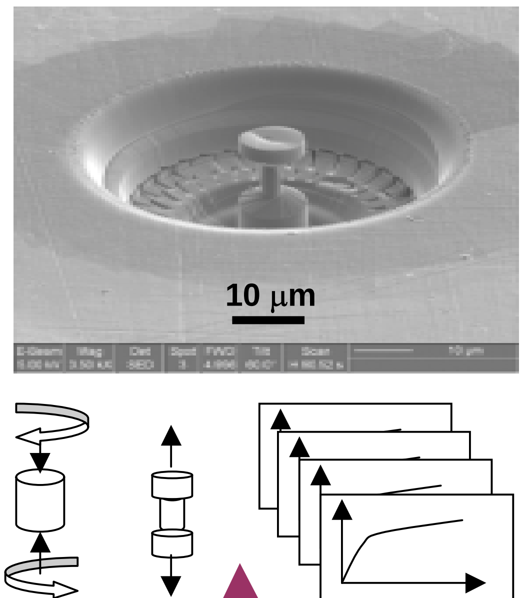
3D sectioning experiments → **3D virtual structure representations**

Advanced simulation & experiments → **intrinsic grain-level properties**

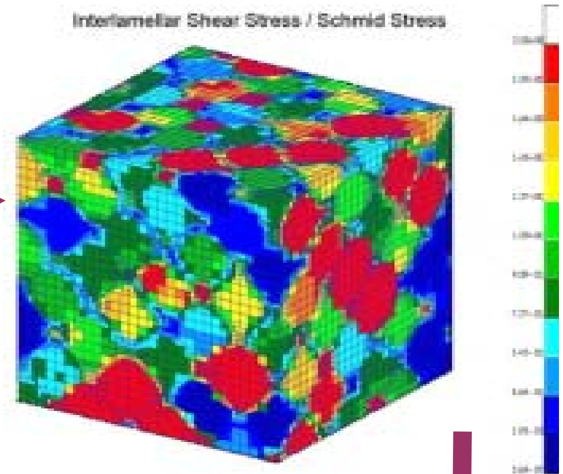
Small-scale property measurements → **model parameterization**

Dimiduk, Parthasarathy, Uchic, and Rao, 2002

Treating Unknown New Materials



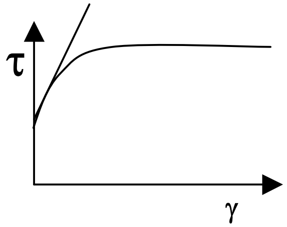
Multiaxial FEM Analysis Of Polycrystalline, Polyconstituent Material



Plastic Heterogeneity & Strain Localization

Properties of <u>R</u>epresentative <u>V</u>olume <u>E</u>lement (RVE) From Mesoscale and Analytical Tools

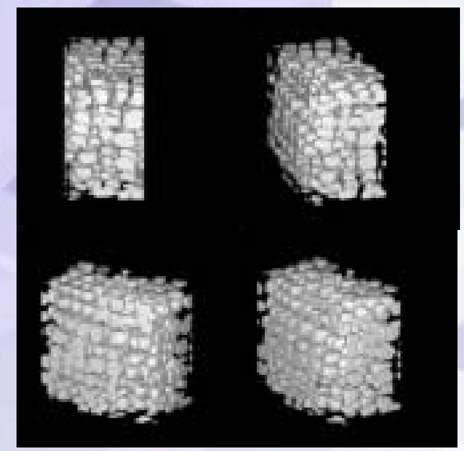
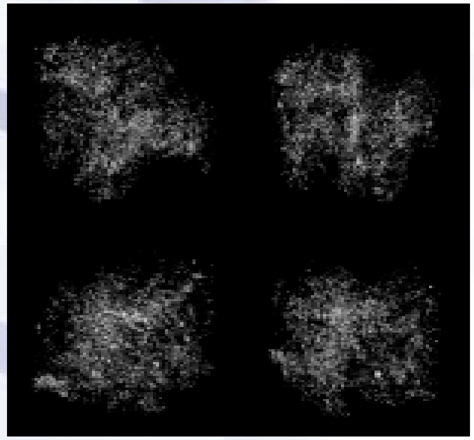
$$\dot{\tau} = \left\{ h - \left(\frac{\tau - \tau_o}{\tau_s - \tau_o} \right) h \right\} \left(\dot{\gamma} \big/ \dot{\gamma}_o \right)^{m}$$



Microstructure-Sensitive Representations (UMATs for 'intrinsic material' RVEs; results used in Ramberg-Osgood or Walker-like forms, or "Curve Generator," etc)

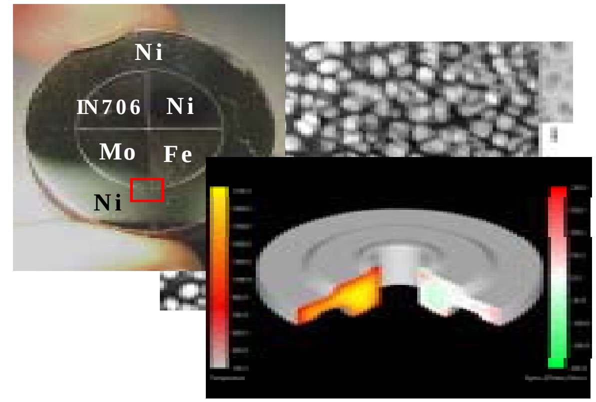
Dimiduk, Parthasarathy, Uchic, and Rao, 2002

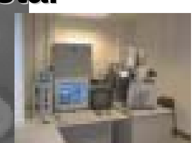
Efficient Experiments for New Materials

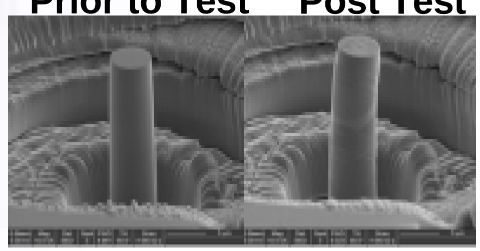
3-Dimensional Characterization of γ' and Carbides

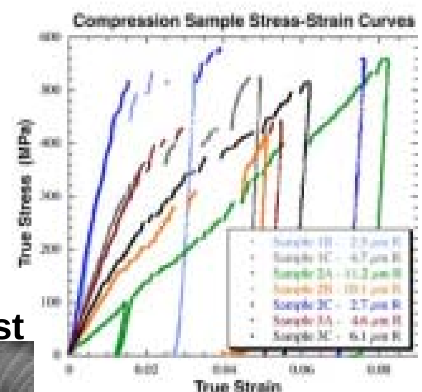
Rapid Experiments, Modeling, & Characterization





Prior to Test | Post Test

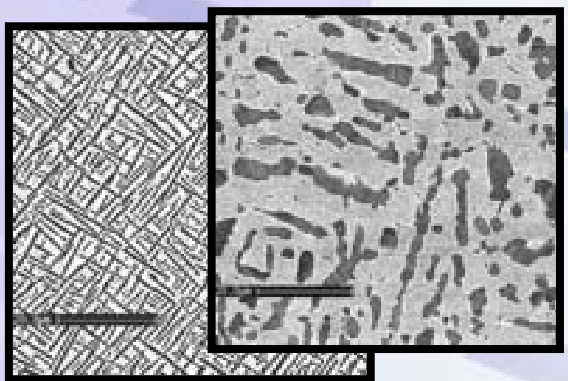


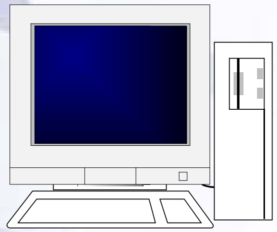


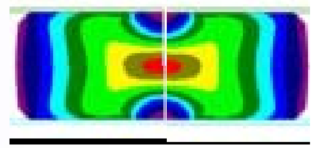
Micro- & Nano-Scale Property Measurement

Unprecedented Novel & Efficient Experiments Emerging!

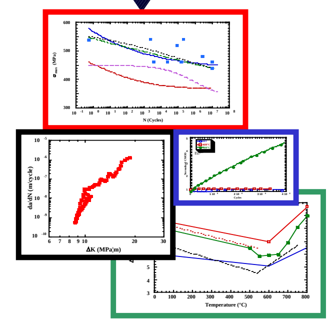
Payoff: Materials & System Prognostics







Materials Mathematics Experiment Experience



Property Database

Mathematics

State Awareness

Failure Physics

Data Fusion

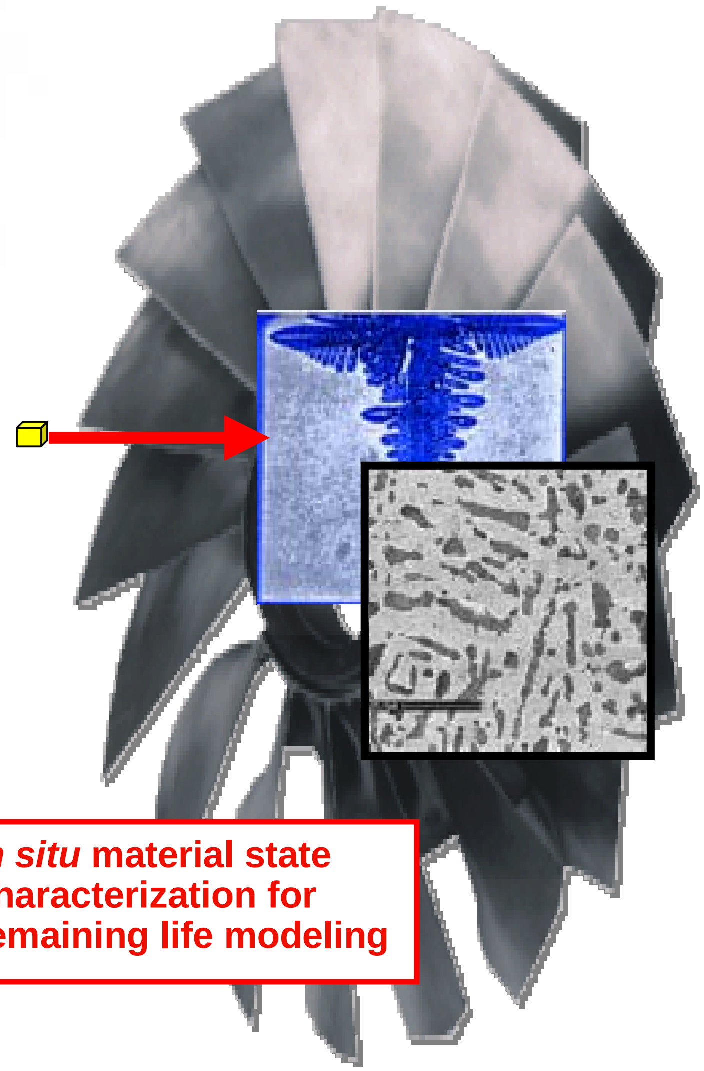
Reasoning System

Combat System Readiness

Prognostics

Material State Definition

- **Characterize each disk's microstructure and damage state at the mesoscale**
- **Utilize DARPA/AF AIM technology – stochastic life prediction**
- **Material state sensing**
  - **Electron backscatter diffraction (EBSD)**
  - **Acoustic attenuation**
  - **Others…**
- **Define the probability of cracking for each disk**



***In situ* material state characterization for remaining life modeling**

MS & E Paradigm