Predicting the Performance of Nuclear Fusion Experiments

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Turbulent Transport is a Grand Challenge in Fusion Modeling
CSPM Studies the Relationship Between Turbulence and Transport with 3 Major Code Suites

- **GYRO/NEO/TGYRO**
  - General Atomics

- **GS2/Trinity**
  - U. Maryland, Oxford

- **GEM**
  - U. Colorado

Turbulence, Transport “Continuum”

Turbulence “PIC”

Emphasis on Physics Fidelity
Turbulence Codes Solve the Gyrokinetic Equation

- Evolution of a 5-dimensional distribution function
  - Coupled PDEs
  - 3 space dimensions, 2 velocity dimensions
- Continuum Codes
  - Evolve function using finite difference/volume and spectral techniques
- PIC Codes
  - Sample distribution function with Monte Carlo particles
Wish-list upgrades for Continuum Turbulence Codes

• Better multi-core performance
• Scalability above 5,000-10,000 processors
• Efficient dense matrix operators
  – Originally designed for problems with banded matrices
  – Next generation physics problems have dense structure
• E. Bass - GYRO
Transport Drivers Use Turbulence Codes

• Output of Turbulence is Input for Transport
  – Diffusion Coefficients, Fluxes
• Turbulence Driver evolves system to equilibrium
  – Time-dependent (Trinity)
  – Time-independent (TGYRO)

\[ \vec{Q}_{\text{code}} = \vec{Q}_{\text{exp}} \]
TGYRO modifies inputs to GYRO/NEO to find root

Independent GYRO Runs
TGYRO is a Newton-Raphson Iterator

- Jacobian calculation is most expensive
  - GYRO ~ < 2000 processors each
  - ~ 500-100k cpu hours per GYRO call
- Phase space can be complicated

2-Point Toy Model
Shows Narrow Valleys and Broad Plains
Computational Challenges for TGYRO

• Speed up Jacobian calculation
  – Extra layers of parallelization
  – Effective load balance

• Efficient Nonlinear Root Finding Method
  – Scales well
  – Robustly handles difficult terrain

• Wall-clock management
  – Time limits prevent many iterations