# Sensitivity and Uncertainty Propagation Needs Beyond Criticality

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## Covariance/Sensitivity/Uncertainty/Validation and Its Impact on Applications

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# Ideal Nuclear Data Pipeline

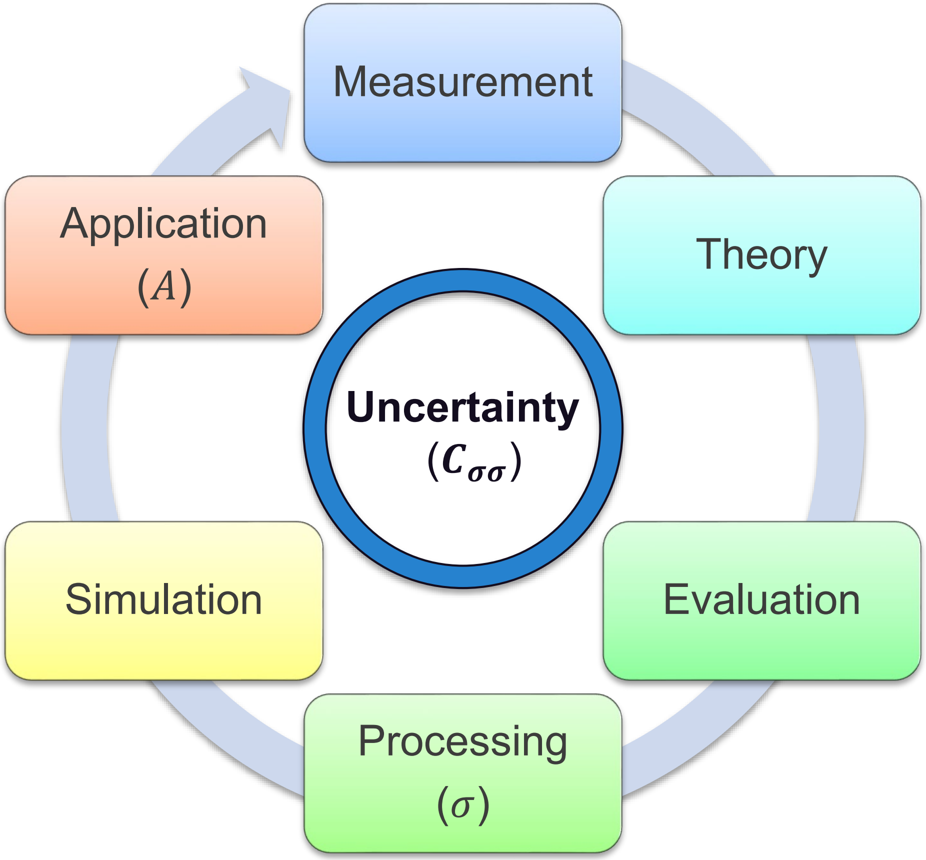
**Sensitivity/perturbation** methods provide efficient uncertainty propagation (UP) to applications and efficient feedback (FB) to the nuclear data evaluation community.

UP: $\mathrm{Var}(A) = S_{A,\sigma}^{T} \boldsymbol{C}_{\boldsymbol{\sigma\sigma}} S_{A,\sigma}$

FB: $A, \sigma, \boldsymbol{C}_{\boldsymbol{\sigma\sigma}} \xrightarrow{\mathrm{GLLS}(s_{A,\sigma})} A', \sigma', \boldsymbol{C}'_{\boldsymbol{\sigma\sigma}}$

Many established methods to compute $S_{A,\sigma}$ for a variety of applications (some limitations).

<u>Each</u> piece of the ND pipeline needs sensitivity/perturbation capabilities.




**Impact of new measurement campaign should be quantified *a priori***

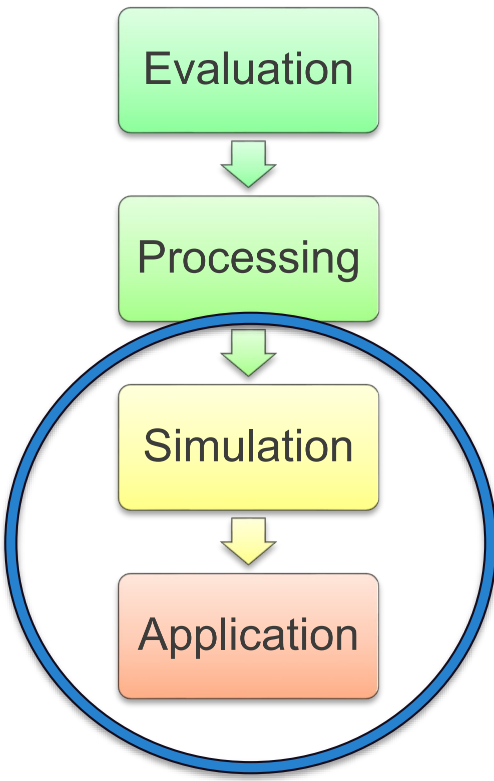
# Focus of Sensitivity/Perturbation Capabilities Has Been Somewhat Limited – Need More Diverse Applications

For both ND uncertainty propagation and feedback, in general:

- Most focus on <u>neutron data</u> (covariances $\boldsymbol{C_{\sigma\sigma}}$), <u>transport simulations</u> (k-eigenvalue) and <u>criticality applications</u> (ICSBEP, reactors)

Many simulation codes (e.g. MCNP, SCALE, Serpent, OpenMC, etc.) can compute various sensitivities/perturbations to ND:

- Fixed-source, k-, and $\alpha$-eigenvalue
- General responses: current, flux, dose, reaction rates
- Other responses
  - diffusion and void reactivity coefficients
  - effective prompt neutron lifetime and delayed neutron fraction




Applications beyond just transport

- Production-depletion
- Time-dependent accident/excursion
- Coupled particle physics
- Advanced detector physics

**Higher-Order Sensitivity Methods Will Be Needed!**

# Focus of Sensitivity/Perturbation Capabilities Has Been Somewhat Limited – Need Developments in Processing

In general, a direct connection between the application and the evaluated ND for both uncertainty propagation and feedback is lacking

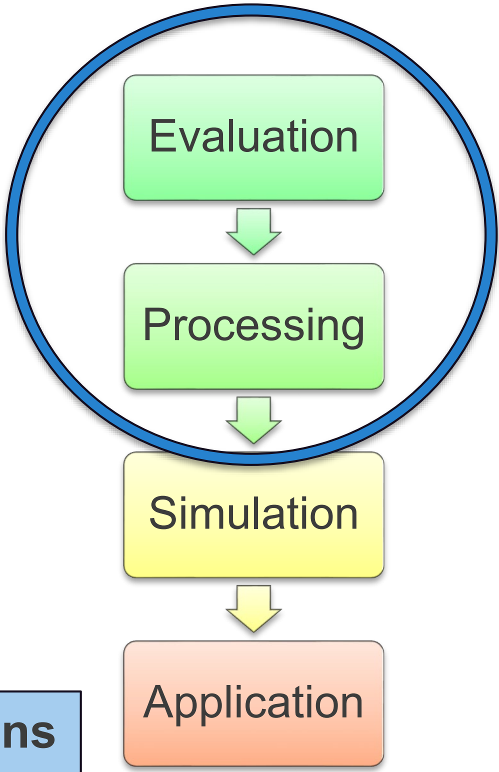
Sensitivity/perturbation methods applied to ND processing

- Improved connection between
  - Evaluated ND (parameters), $p$
  - Processed ND, $\sigma$
- Applies to evaluated ND and covariances

$$S_{A,p} \sim S_{A,\sigma}\, S_{\sigma,p}$$

Applications of sensitivity/perturbation processing

- Resonance parameters
- Thermal scattering
- Temperature (doppler broadening)
- Multigroup weighting function




**Direct and Efficient UP from Evaluation to Applications**
**Direct and Efficient FB from Applications to Evaluation**

# Without Sensitivities, All Is Not Lost – Sampling-Based (Derivative-Free) Methods Are Good Too

Uncertainty Propagation, Evaluation ➞ Application

- Monte Carlo methods
  - Brute force
  - MCMC
  - LHS
- Stochastic collocation methods
- Central differencing (sensitivities)

Feedback to ND, Application ➞ Evaluation

- Monte Carlo methods
  - Total MC (TMC)
  - Unified MC (UMC)
  - TMC+UMC
- Derivative-free optimization
  - MADS, NOMAD
  - Genetic algorithms
  - Other ML/AI methods

**Benefits**

- **Creating replica data is generally straightforward**
- **Processing and simulation steps need no change**
- **Handles nonlinearities in complex applications**
- **When converged, provides accurate results**

**Limitations**

- **Non-physical replicas**
- **Can be orders of magnitude more computationally expensive (potentially intractable)**