Hexagonal Nodal Diffusion in Ants

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Serpent UGM

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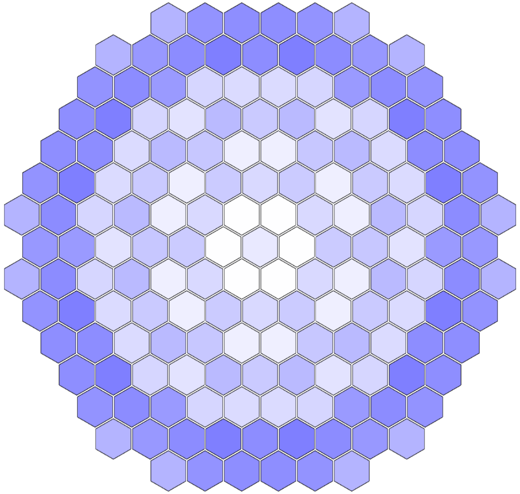


Outline

Background

- Kraken and Ants

Solution method

- Outlines of the solution method

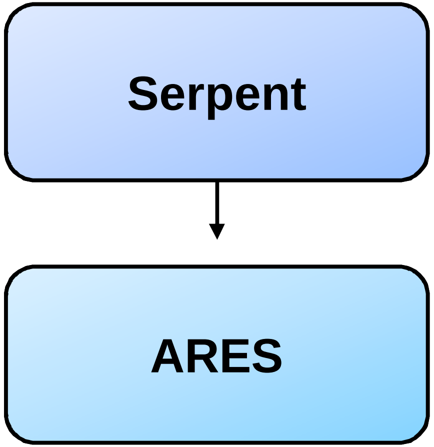
AER FCM-101 Benchmark

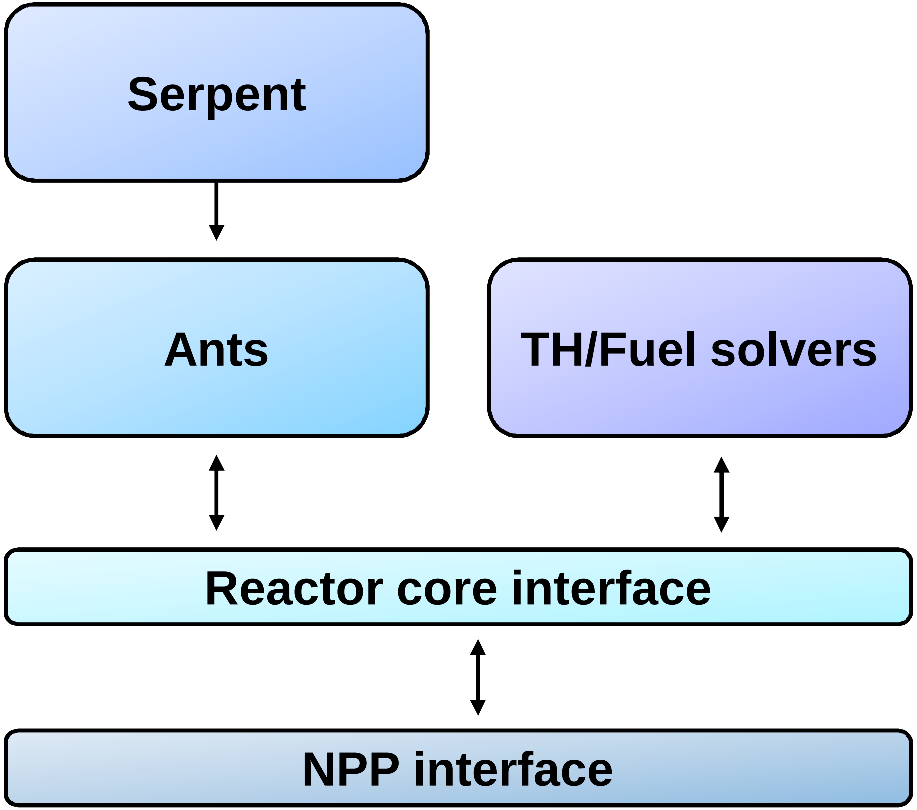
- Specification
- Results

X2 VVER-1000 Fresh Core Benchmark – HZP case

- Specification
- Results

Background


Serpent
ARES


Serpent
Ants
TH/Fuel solvers
Reactor core interface
NPP interface

Ants

Deterministic nodal neutronics solver module for relatively light-weight calculations

Scope for computational resources

- For example, 1 to 32 CPU cores on the same shared-memory platform

Future aim

- Handling the neutronics of routine burnup and transient analysis calculations
- Platform for developing group constant generation with Serpent
- Currently: Ants is functional for steady state calculations in rectangular and hexagonal assembly geometries

Solution method

Based on

- AFEN (Analytic Function Expansion Nodal)[1]
- FENM (Function Expansion Nodal Method)[2]

Features

- Large number of unknowns/degrees of freedom per node
- Slower than transverse integration
- Avoids transverse integration – significant benefit for hexagonal geometry

1: N. Z. Cho and J. M. Noh. “Analytic Function Expansion Nodal Method for Hexagonal Geometry.” Nuclear Science and Engineering, volume 121, pp. 245–253 (1995).

2: B. Xia and Z. Xie. “Flux expansion nodal method for solving multigroup neutron diffusion equations in hexagonal-z geometry.” Annals of Nuclear Energy, volume 33, pp. 370–376 (2006).

Solution method

Intranodal flux is expanded using analytic basis functions.

$$-\nabla^2\vec{\phi}(\vec{r}) + L\vec{\phi}(\vec{r}) = 0,$$

$$L = D^{-1}\left(A - \frac{\chi}{k_{\text{eff}}}F^T\right),$$

$$L = U\Lambda U^{-1},$$

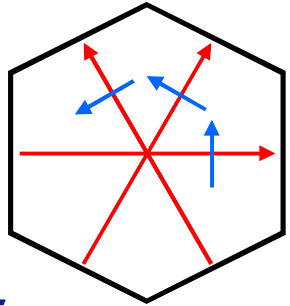
$$\vec{\psi}(\vec{r}) = U^{-1}\vec{\phi}(\vec{r})$$

Flux expansion

If all eigenvalues are real, the result is G decoupled equations for eigenmode fluxes:

$$-\nabla^2\psi_m(\vec{r})+\lambda_m\psi_m(\vec{r})=0,\ m=1,\ldots,G,$$

For these, sets of analytic solutions can be found. For hexagonal geometry, Ants uses three radial directions + their linear transverse gradients. Axially there is simple SN/CN.



$$C_{m,i}\mathrm{SN}\left(k_m\vec{r}\cdot\hat{r}\right)+C_{m,i+1}\mathrm{CN}\left(k_m\vec{r}\cdot\hat{r}\right)$$

$$C_{m,j}(\vec{s}\cdot\hat{r})\mathrm{SN}\left(k_m\vec{r}\cdot\hat{r}\right)+C_{m,j+1}(\vec{s}\cdot\hat{r})\mathrm{CN}\left(k_m\vec{r}\cdot\hat{r}\right)$$

$$\vec{s}\perp\vec{r}$$

Using the flux expansion

C = coefficients of the flux expansion

$$Q_{\text{in}} C = J^{+}$$

$$Q_{\text{out}} C = J^{-}$$

$$J^{-} = Q_{\text{out}} Q_{\text{in}}^{-1} J^{+} = R J^{+}$$

Here vectors J are 20*G vectors of partial neutron current moments.

AER FCM-101 Benchmark 1/3

VVER-1000 3D diffusion benchmark[3]

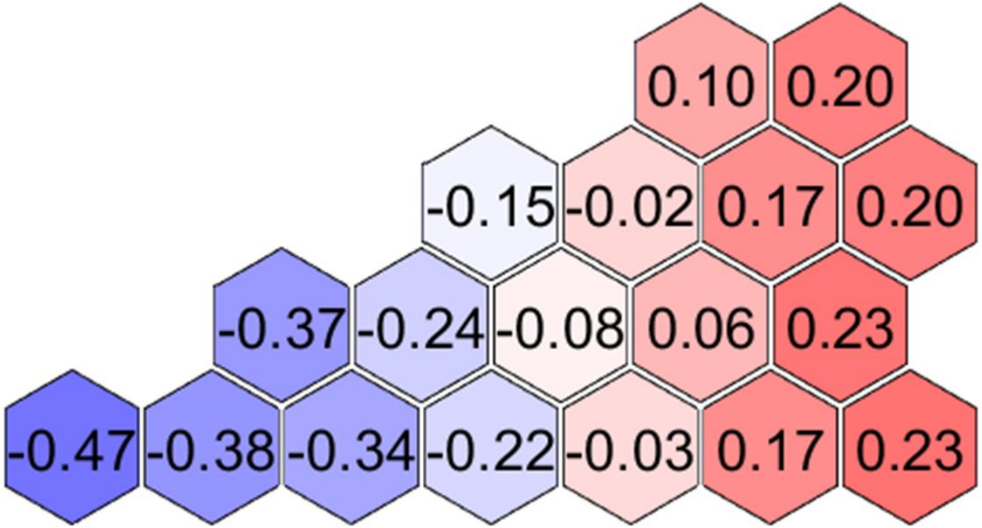
- 30 deg. symmetry
- Group constants provided as input
  - Two group problem
- Partially inserted control rods
- Zero-incoming boundary conditions

Results

- k_{eff} and power distribution from Ants
- Comparison to SIMULATE5 and DYN3D
- Extrapolated CRONOS finite element solution as a reference

3: AER benchmark book, http://aerbench.kfki.hu/ [accessed 29.5.2018]

AER FCM-101 Benchmark 2/3



$100 \times |\Delta P|_{max}$

Slight tilt from middle to the edges

AER FCM-101 Benchmark 3/3

Case	$100\times\lvert\Delta P\rvert_{\mathrm{max}}$	ΔP_{rms} (%)	k_{eff}	Δk_{eff} (pcm)
CROCUS (ref.)	–	–	1.049526	–
Ants	0.47	0.20	1.049678	15
DYN3D HEXNEM3	0.41	0.22	1.04945	–7
SIMULATE5-HEX	0.31	0.18	1.04971	18

X2 VVER-1000 Benchmark 1/3

Description of first 4 cycles of the unit 2 of Khmelnitsky NPP[4]

- Here, HZP critical state of the fresh core is examined
- Partially inserted control rods
- Measurements available
  - Here measurements are omitted: 3D full core Serpent calculation is used as a reference

Group constants

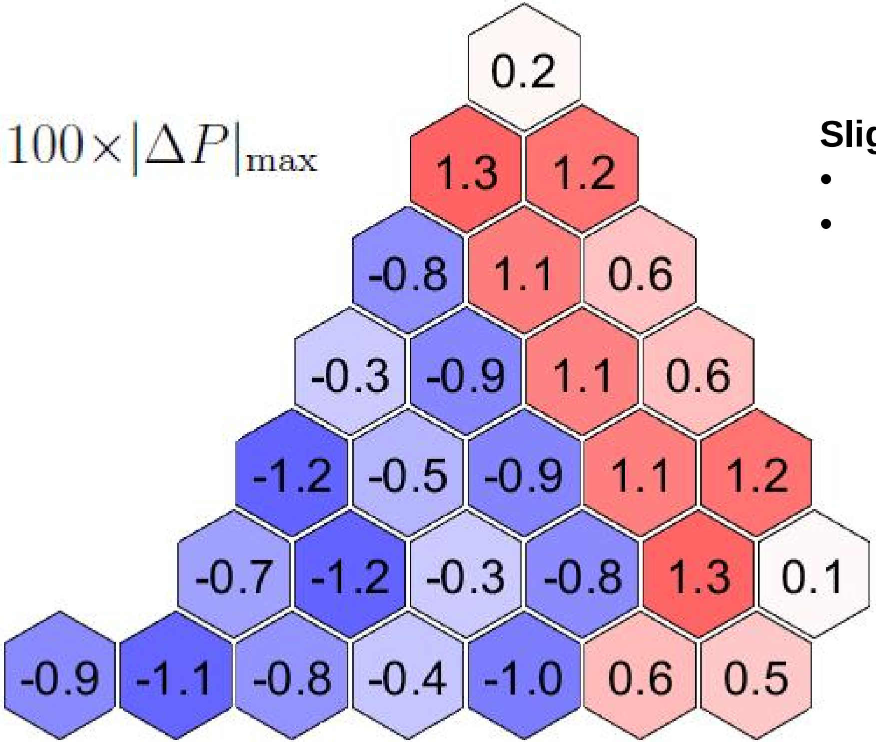
- Provided by Dr. Bilodid

Serpent 3D full core results

- Also provided by Dr. Bilodid
  - See [5]

4: Lötsch, T., Khalimonchuk, V., Kuchin, A., 2009. Proposal of a benchmark for core burnup calculations for a VVER-1000 reactor core., in: Proceedings of the 19th AER Symposium on VVER Reactor Physics and Reactor Safety
5: Y. Bilodid, U. Grundmann, S. Kliem, "The HEXNEM3 nodal flux expansion method for the hexagonal geometry in the code DYN3D", Annals of Nuclear Energy, Vol. 116 p. 187-194, June 2018

X2 VVER-1000 Benchmark 2/3



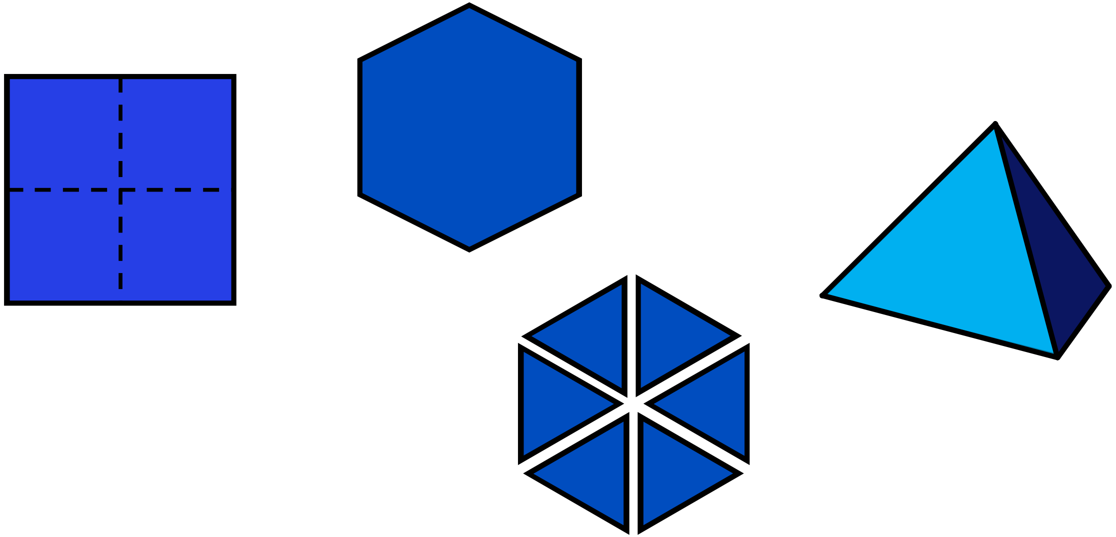
Slight tilt at the core edge in the difference

- From the Serpent solution
- Diffusion solution is symmetric

X2 VVER-1000 Benchmark 3/3

Case	$100 \times \|\Delta P\|_{max}$	ΔP_{rms} (%)	k_{eff}	Δk_{eff} (pcm)
Serpent 2 (ref.)	–	–	1.000692	–
Ants	1.34	0.89	1.001681	99
DYN3D HEXNEM3	1.32	0.74	1.001442	75

Bonus Slide



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through science-based innovations.