Introduction to OPAL - Part 1

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Outline

OPAL in a Nutshell

OPAL is a tool for charged-particle optics in accelerator structures and beam lines. The main focus is on 3D modelling and handling of large structures.

- OPAL is derived from MAD9P and is based on the CLASSIC class library.
- Independent Parallel Particle Layer (IPPL) is the framework which provides parallel particles and fields using data parallel ansatz.
- OPAL is build from ground up as a parallel application having in mind that: High Performance Computing (HPC) is the third leg of science, which complements theory and the experiment.
- OPAL runs on your laptop as well as on the largest HPC clusters.
- OPAL uses the MAD language with extensions.
- OPAL (and all other used frameworks) are written in C++ using OO-techniques, hence OPAL is very easy to extend.
- Documentation is taken very serious at both levels: source code and user manual. Checkout: `http://amas.web.psi.ch/docs/index.html`.

OPAL Flavours

The following OPAL flavours exist:

- OPAL-MAP (not yet released)
  - OPAL-MAP tracks particles with 3D space charge using split operator techniques, and is a proper subset of MAD9P .
- OPAL-T
  - OPAL-T tracks particles which 3D space charge uses time as the independent variable, and can be used to model guns, injectors and complete XFEL's but without the undulator.
- OPAL-CYCL
  - OPAL-CYCL tracks particles which 3D space charge including neighbouring turns in cyclotrons with time as the independent variable.

OPAL Flavours

Sketch of an inputfile - OPAL-T

```
TITLE,STRING="OPAL XFEL 30 MeV Diagnostics section";
Edes=0.0307;      // GeV
gamma=(Edes+EMASS)/EMASS;

FINLB02_MSLAC40: SOLENOID, L=0.001, KS=0.05,
FMAPFN="FINLB02-MSLAC.T7", ELEMEDGE=4.554;

FIND1_MQ10: QUADRUPOLE, L=0.1, K1=2.788, ELEMEDGE=5.874;

FIND1:   LINE = (FINLB02_MSLAC40, FIND1_MQ10 ...);

Dist1:DISTRIBUTION, DISTRIBUTION=GAUSS,
SIGMAX=  1.0e-03, SIGMAPX=1.0e-4, CORRX=0.5,
SIGMAY=  2.0e-03, SIGMAPY=1.0e-4, CORRY=-0.5,
SIGMAT=  3.0e-03, SIGMAPT=1.0e-4, CORRT=0.0;
```

OPAL Flavours

Sketch of an inputfile - OPAL-T cont.

```
Fs2:FIELDSOLVER, FSTYPE=FFT, MX=32, MY=32, MT=64,
        PARFFTX=false, PARFFTY=false, PARFFTT=true,
        BCFFTX=open, BCFFTY=open, BCFFTT=open,
        BBOXINCR=1.0, GREENSF=INTEGRATED;

beam1: BEAM, PARTICLE=ELECTRON, PC=P0, NPART=1e5,
BFREQ=1498.953425154e6, BCURRENT=0.299598, CHARGE=-1;

SELECT, LINE=FIND1;

TRACK,LINE=FIND1, BEAM=beam1, MAXSTEPS=10000, DT=1.0e-12;
 RUN, METHOD = "PARALLEL-T", BEAM=beam1,
 FIELDSOLVER=Fs2, DISTRIBUTION=Dist1;
endtrack;
Stop;
```

$$\mathbf{curl}\,\boldsymbol{E} + \frac{\partial \boldsymbol{B}}{\partial t} = 0$$

$$\mathrm{div}\,\boldsymbol{B} = 0$$

$$\mathrm{div}\,\boldsymbol{E} = \rho/\varepsilon_0$$

Lie Algebraic Methods

Magnetic Optics

$$\boldsymbol{H} = \boldsymbol{H}_{\mathrm{ext}} + \boldsymbol{H}_{\mathrm{sc}}$$

N-Body Dynamics

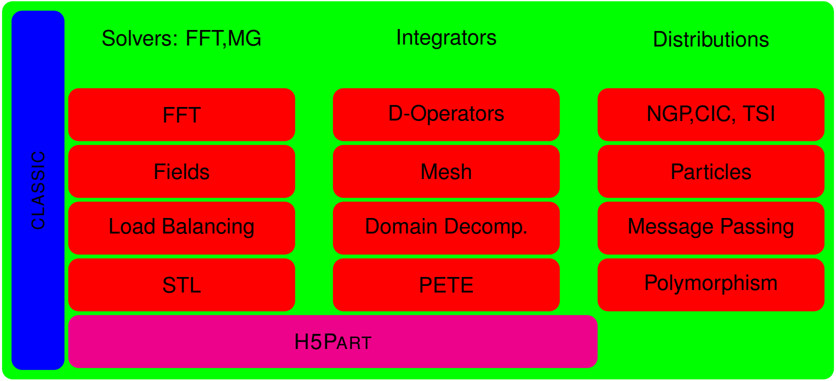
3D Poisson Solver

$$\mathcal{M}(s) = \mathcal{M}_{\mathrm{ext}}(s/2) \otimes \mathcal{M}_{\mathrm{sc}}(s) \otimes \mathcal{M}_{\mathrm{ext}}(s/2) + \mathcal{O}(s^3)$$

RK-4 and the implicit D_1 scheme [1]

[1] Birdsall & Langdon "Plasma Physics via Computer Simulation

Architecture

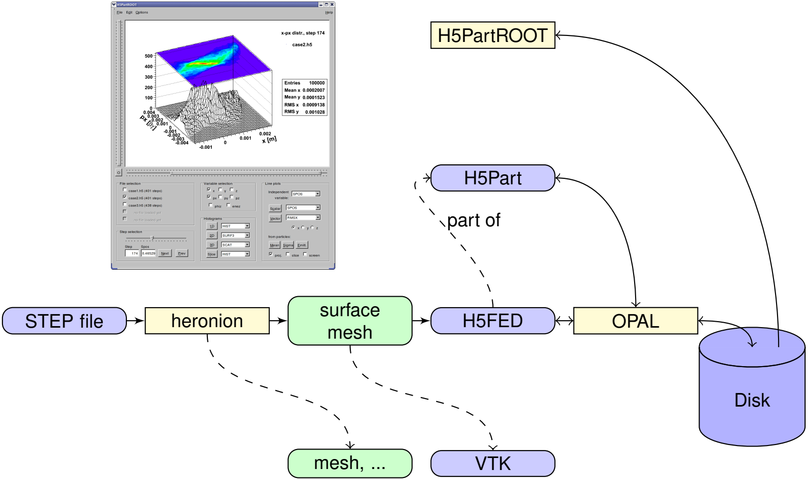


- **OPAL Object Oriented Parallel Accelerator Library**
- IP^2L Independent Parallel Particle Layer
- CLASSIC Class Library for Accelerator Simulation System and Control
- **H5PART for parallel particle and structured field I/O (HDF5)**

Architecture

Connection with other Frameworks

H5PartROOT



in collaboration with B. Oswald and A. Gsell (AIT)

Parallel Issues

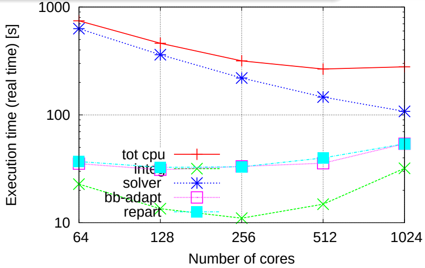
OPAL Scaling on Cray XT3 "Horizon" at CSCS

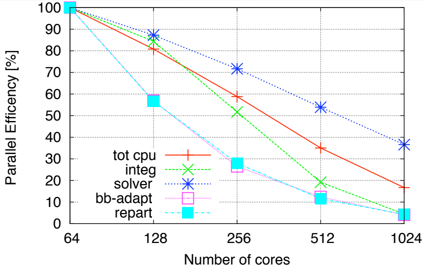
Production Run Setup

- Tracking 10^7 particles
- 3D FFT on a 256^3 grid
- Gaussian distribution
- no parallel I/O

Observations

- Solver scales still well
- Load balancing not optimal anymore
- Moving mesh has a problem





- 3D FFT ($G_1 = 2048^3$, $G_2 = 4096^3$)
- 2D domain decomposition, $P = 512 \ldots 4096$[a]
- Kernel scales very well

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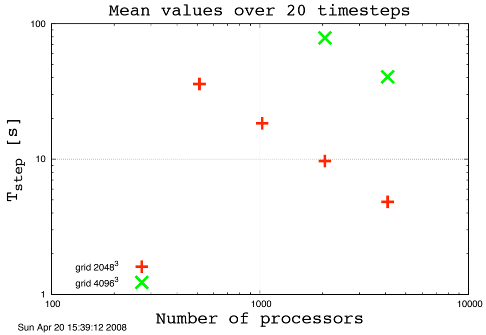
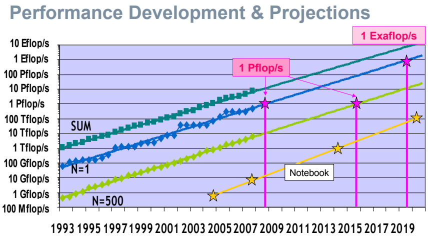
[a] obtained on Franklin (Cray XT4 at LBNL) number 5 on the Top-500



Parallel Issues

Reality or Fiction?

Your Laptop would be at the bottom of the Top-500 list in 1998!



Source: H. Meuer, http://www.top500.org/files/TOP500_Looking_back_HWM.pdf

Our FELSI-cluster would be number one of the Top-500 list in 1997!

Implications

Using the technology ahead will enable us to speedup computations while increasing the accuracy of the used models. We can enter into new regimes of accelerator modelling and controls.

OPAL V 1.1.0 Release & Feature Roadmap

Name	**Version (estimated)**
Algorithms	
longitudinal and transverse short range wake fields	end of summer 1.1.3
ML based space charge solver	1.1.1
1D csr wake fields	1.1.1
3D(2D) FETD self-consistent solver	1.x
OPAL-MAP	1.x
Bet/HOMDYN Model (Envelope Solver)	end of summer 1.1.3
Elements	
SBend	1.1.0
Quadrupole	1.1.0
Multipole	1.1.x
Collimator	1.1.1
Screen	1.1.0

Table: List of features which will be implemented in versions to come (please note: the estimated version numbers are non-binding).