GridPACK™ Toolkit for Developing Power Grid Simulations on High Performance Computing Platforms

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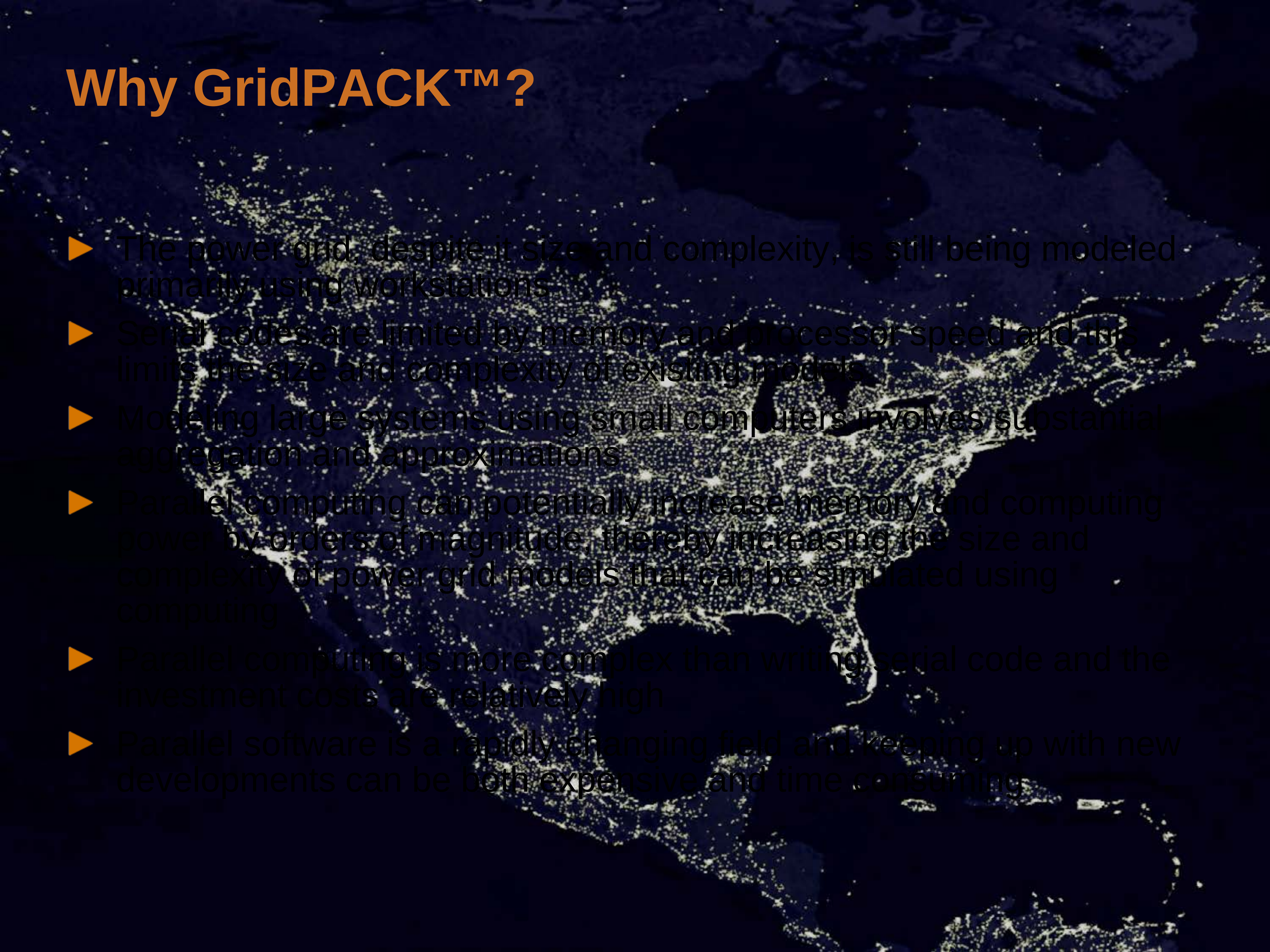
GridPACK™ Development Team

- Bruce Palmer (PI): Parallel code development
- William Perkins: Parallel code development
- Yousu Chen: Power grid application development
- Shuangshuang Jin: Power grid application development
- David Callahan: Data integration
- Kevin Glass: Data integration and optimization
- Ruisheng Diao: Power grid engineering and model validation
- Stephen Elbert: Optimization and economic modeling
- Mallikarjuna Vallem: Synthetic data and model validation
- Nathan Tenney: Automatic builds and testing
- Kevin Lai: Webpage development
- Zhenyu (Henry) Huang: Program management

Why GridPACK™?



- The power grid, despite it size and complexity, is still being modeled primarily using workstations
- Serial codes are limited by memory and processor speed and this limits the size and complexity of existing models
- Modeling large systems using small computers involves substantial aggregation and approximations
- Parallel computing can potentially increase memory and computing power by orders of magnitude, thereby increasing the size and complexity of power grid models that can be simulated using computing
- Parallel computing is more complex than writing serial code and the investment costs are relatively high
- Parallel software is a rapidly changing field and keeping up with new developments can be both expensive and time consuming

Objectives

- Simplify development of HPC codes for simulating power grid
- Create high level abstractions for common programming motifs in power grid applications
- Encapsulate high performance math libraries and make these available for power grid simulations
- Promote reuse of power grid software components in multiple applications to reduce development and maintenance costs
- Incorporate as much communication and indexing calculations as possible into high level abstractions to reduce application development complexity
- Compartmentalize functionality to reduce maintenance and development costs

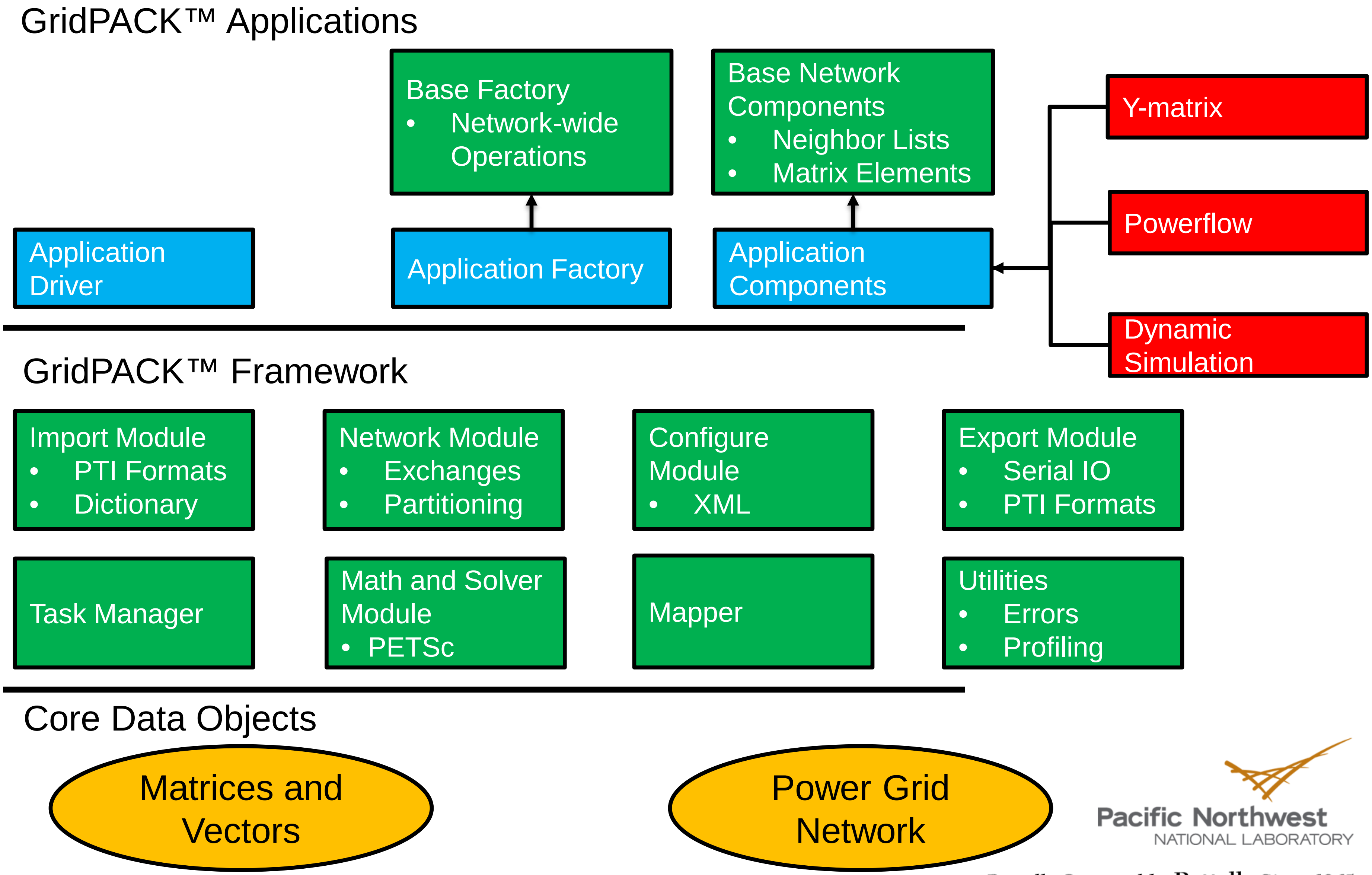
Impact

- Access to larger computers with more memory and processing power
- Models containing larger networks and higher levels of detail can be simulated
- Reduced time to solution
- Greater capacity for modeling contingencies and quantifying uncertainty

Contributing to GridPACK™

- GridPACK™ is open-source, releases include all source files
- BSD license allows users to incorporate GridPACK™ in their software, both proprietary and open-source
- Development tree will be available via a public server in the late summer to fall time frame (most likely via GitHub)
- Files can be contributed in the meantime by getting in touch with a member of the development team

GridPACK™ Framework



GridPACK™ Applications

Base Factory
- Network-wide Operations

Base Network Components
- Neighbor Lists
- Matrix Elements

Y-matrix

Powerflow

Dynamic Simulation

Application Driver

Application Factory

Application Components

GridPACK™ Framework

Import Module
- PTI Formats
- Dictionary

Network Module
- Exchanges
- Partitioning

Configure Module
- XML

Export Module
- Serial IO
- PTI Formats

Task Manager

Math and Solver Module
- PETSc

Mapper

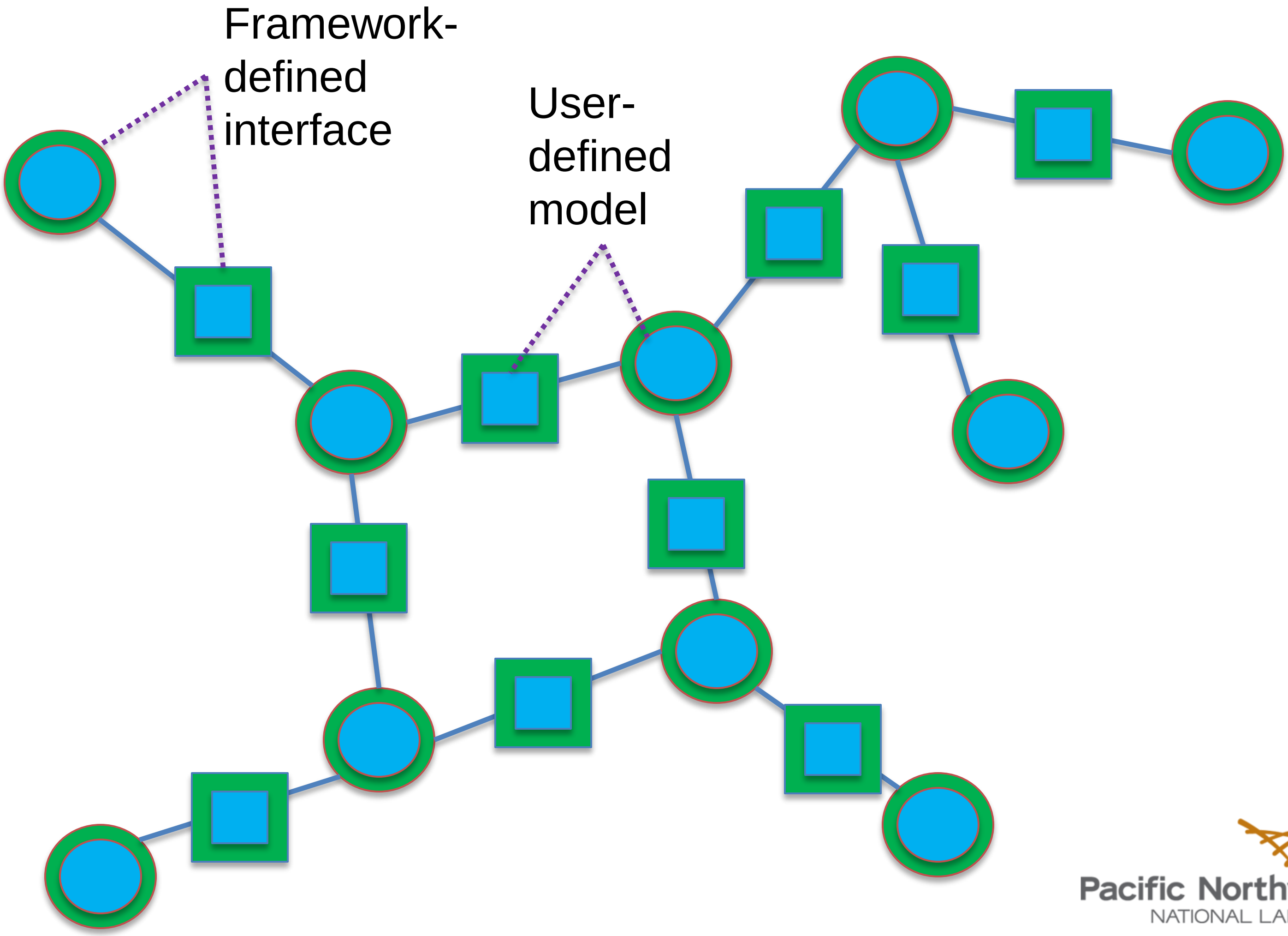
Utilities
- Errors
- Profiling

Core Data Objects

Matrices and Vectors

Power Grid Network

Schematic Diagram of Network Object

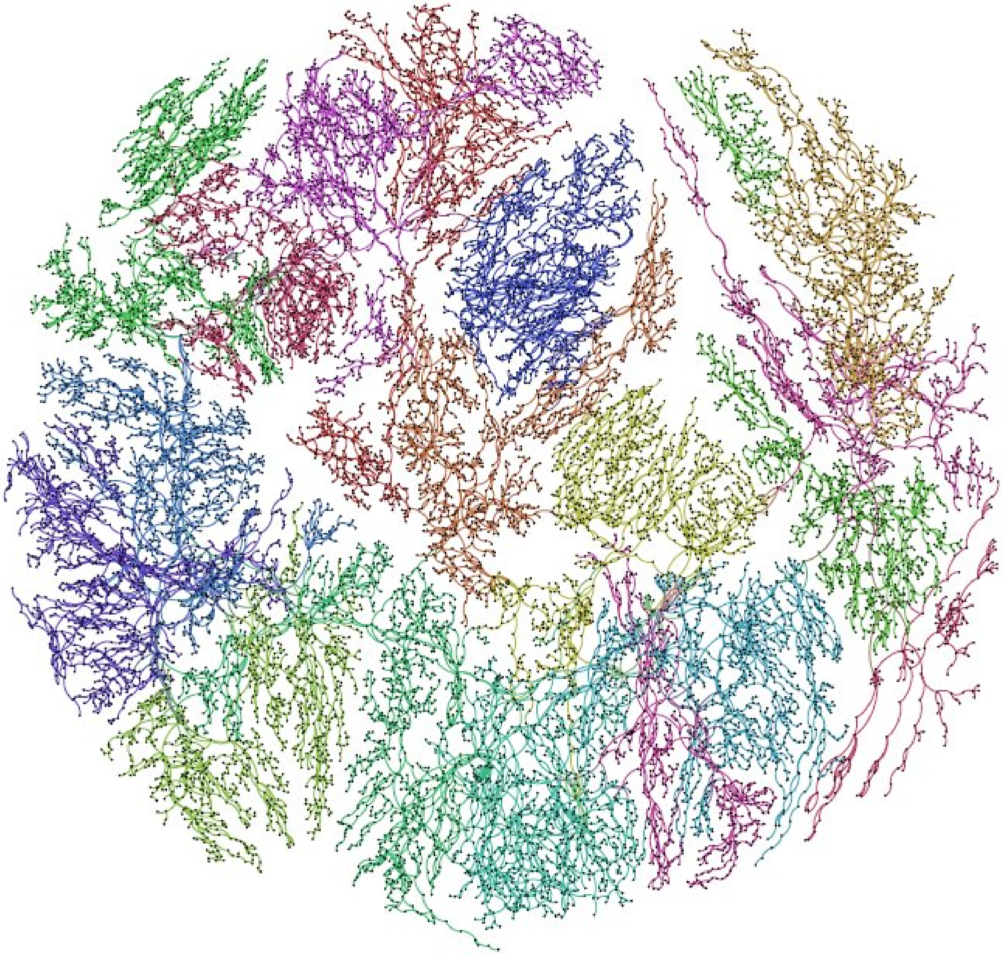


Framework-defined interface

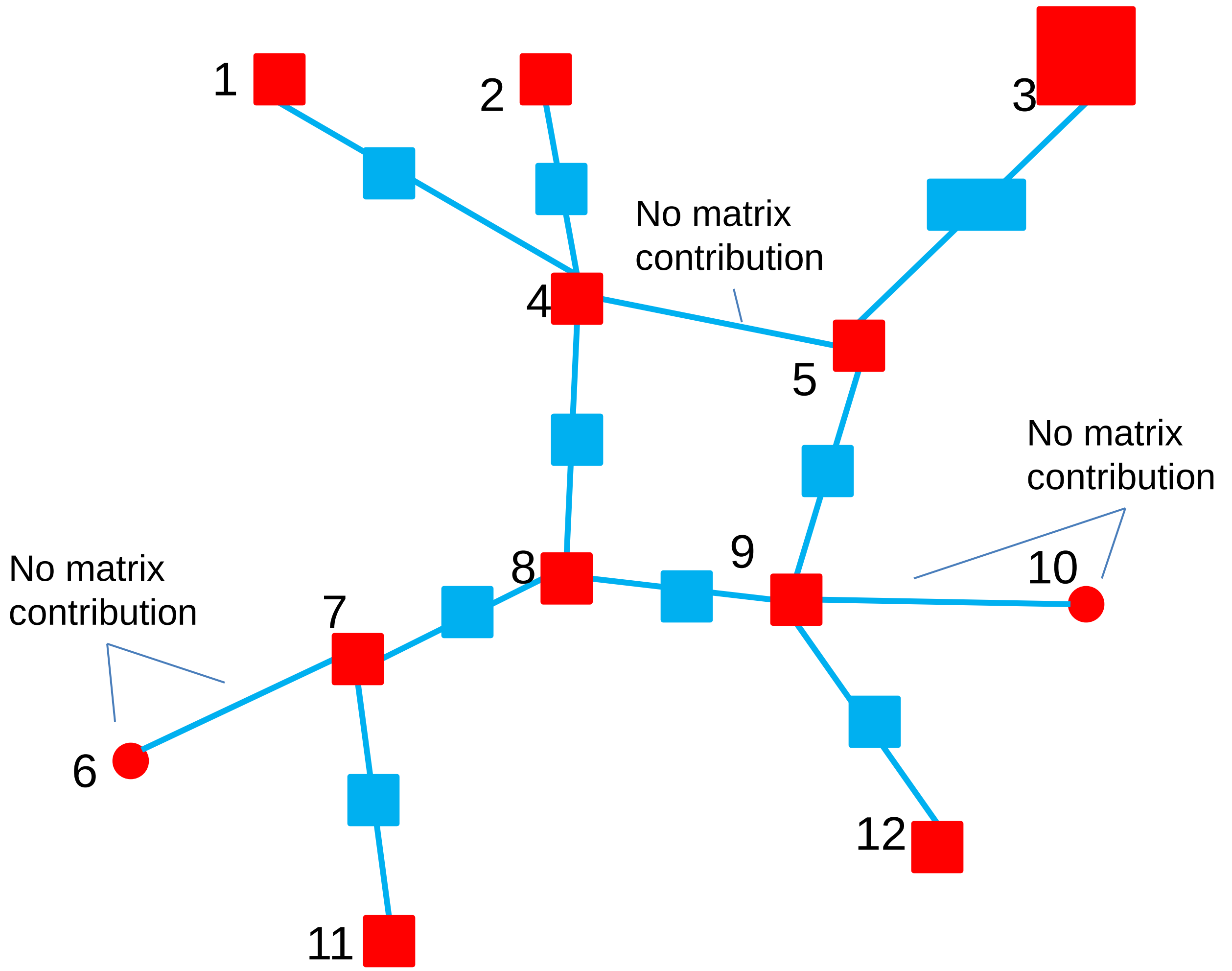
User-defined model

Partitioning of Network

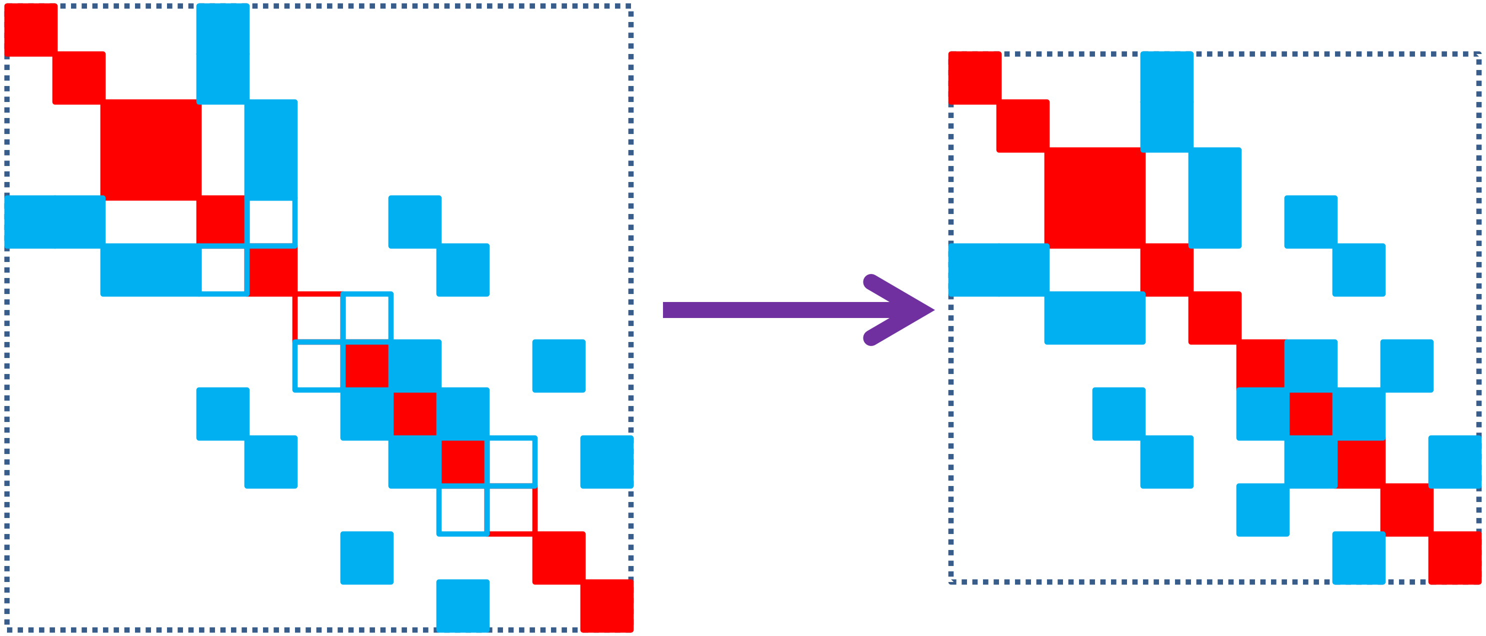
WECC (Western Electricity Coordinating Council) network partitioned between 16 processors



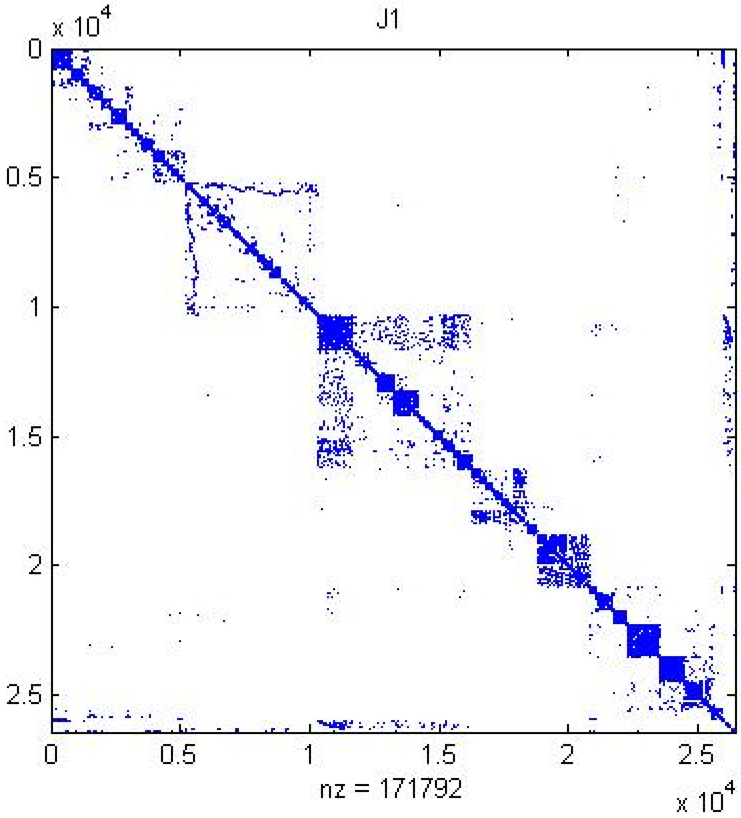
Matrix Contributions from Network Components



Distribute Component Contributions and Eliminate Gaps

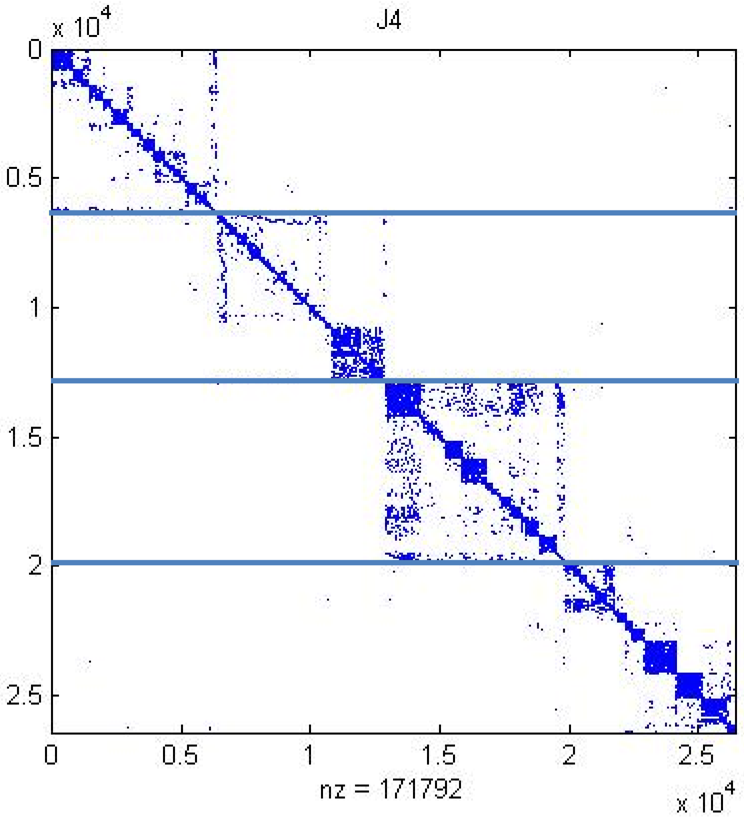


Powerflow Jacobian from Mapper (1 Processor)



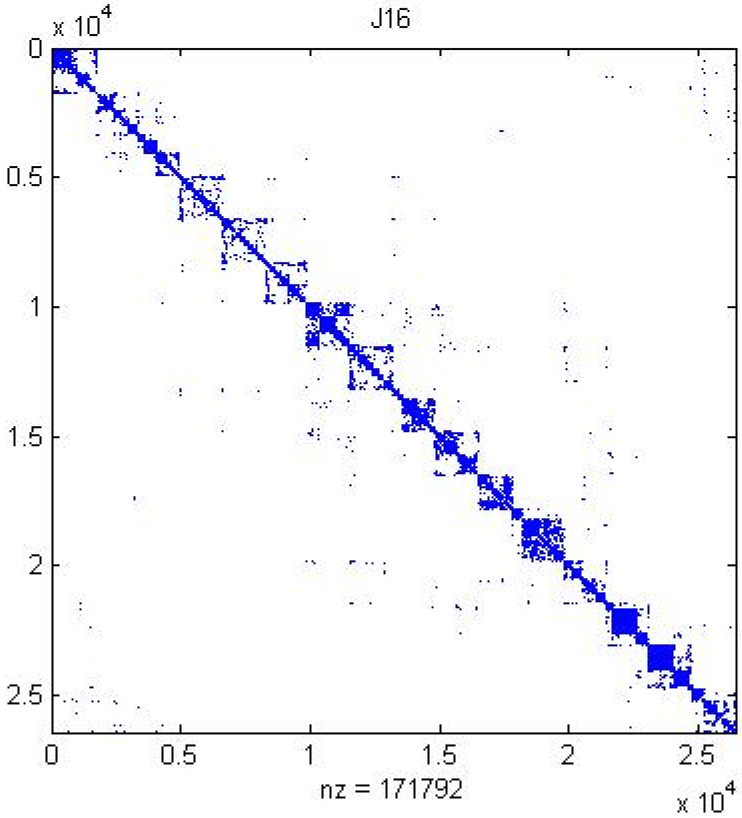
16351 bus
WECC
system

Powerflow Jacobian from Mapper (4 Processor)



16351 bus
WECC
system

Powerflow Jacobian from Mapper (16 Processor)



16351 bus
WECC
system

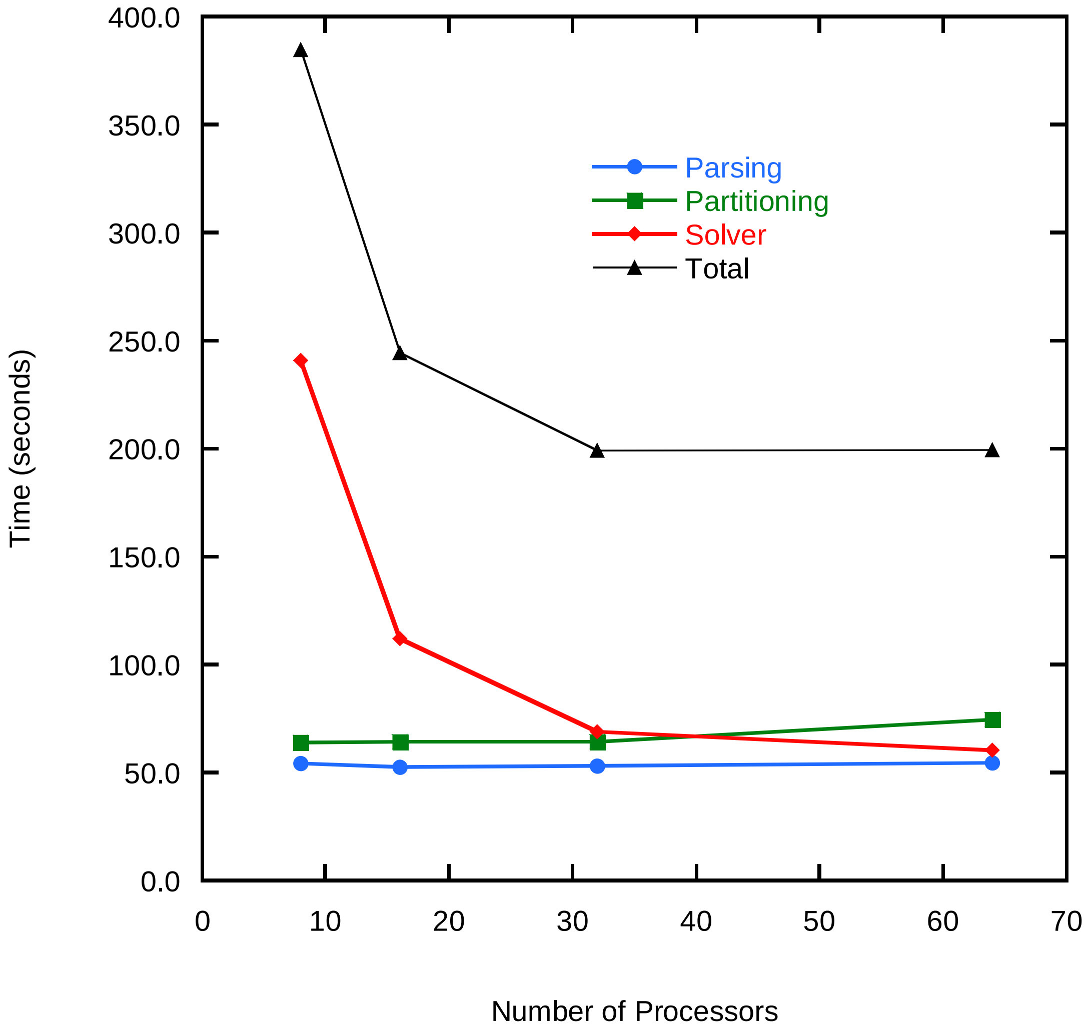
Powerflow Code

```
typdef BaseNetwork<PFBus,PFBranch> PFNetwork;
Communicator world;
shared_ptr<PFNetwork>
    network(new PFNetwork(world));

PTI23_parser<PFNetwork> parser(network);
parser.parse("network.raw");
network->partition();

PFFactory factory(network);
factory.load();
factory.setComponents();
factory.setExchange();

network->initBusUpdate();
factory.setYBus();
factory.setMode(YBus);
FullMatrixMap<PFNetwork> mMap(network);
shared_ptr<Matrix> Y = mMap.mapToMatrix();

factory.setSBus();
factory.setMode(RHS);
BusVectorMap<PFNetwork> vMap(network);
shared_ptr<Vector> PQ = vMap.mapToVector();
factory.setMode(Jacobian);
FullMatrixMap<PFNetwork> jMap(network);
shared_ptr<Matrix> J = jMap.mapToMatrix();
shared_ptr<Vector> X(PQ->clone());

double tolerance = 1.0e-6;
int max_iteration = 100;
ComplexType tol = 2.0*tolerance;
LinearSolver solver(*J);

int iter = 0;

// Solve matrix equation J*X = PQ
solver.solve(*PQ, *X);
tol = X->norm2();

while (real(tol) > tolerance &&
iter < max_iteration) {
  factory.setMode(RHS);
  vMap.mapToBus(X);
  network->updateBuses();
  vMap.mapToVector(PQ);
  factory.setMode(Jacobian);
  jMap.mapToMatrix(J);
  solver.solve(*PQ, *X);
  tol = X->normInfinity();
  iter++;
}
```

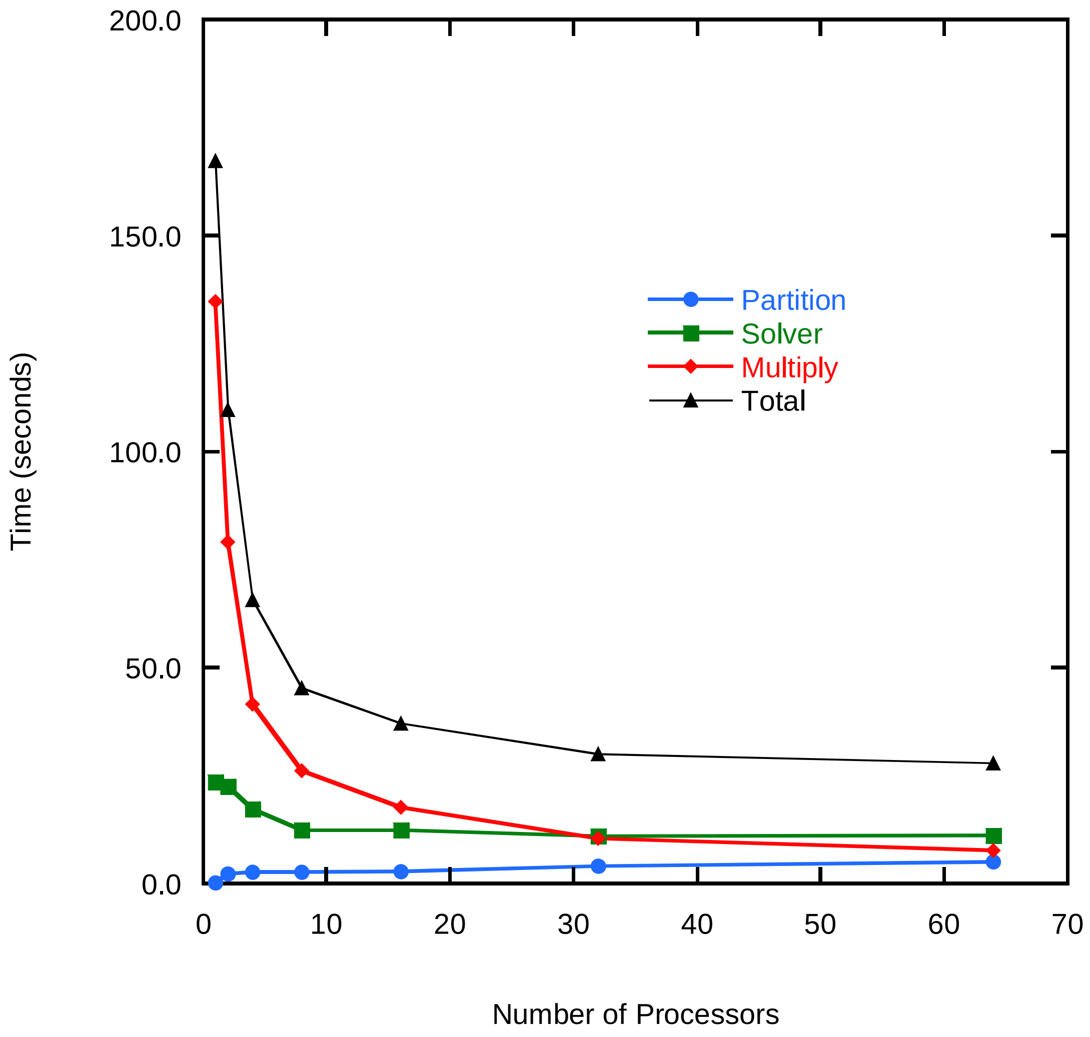
Performance Results

- Applications
  - Powerflow
  - Dynamic Simulation
  - Dynamic Contingency Analysis
- Strong Scaling Performance
  - Fixed problem size, increasing number of processors

Powerflow Scaling for Artificial 777646 Bus Network

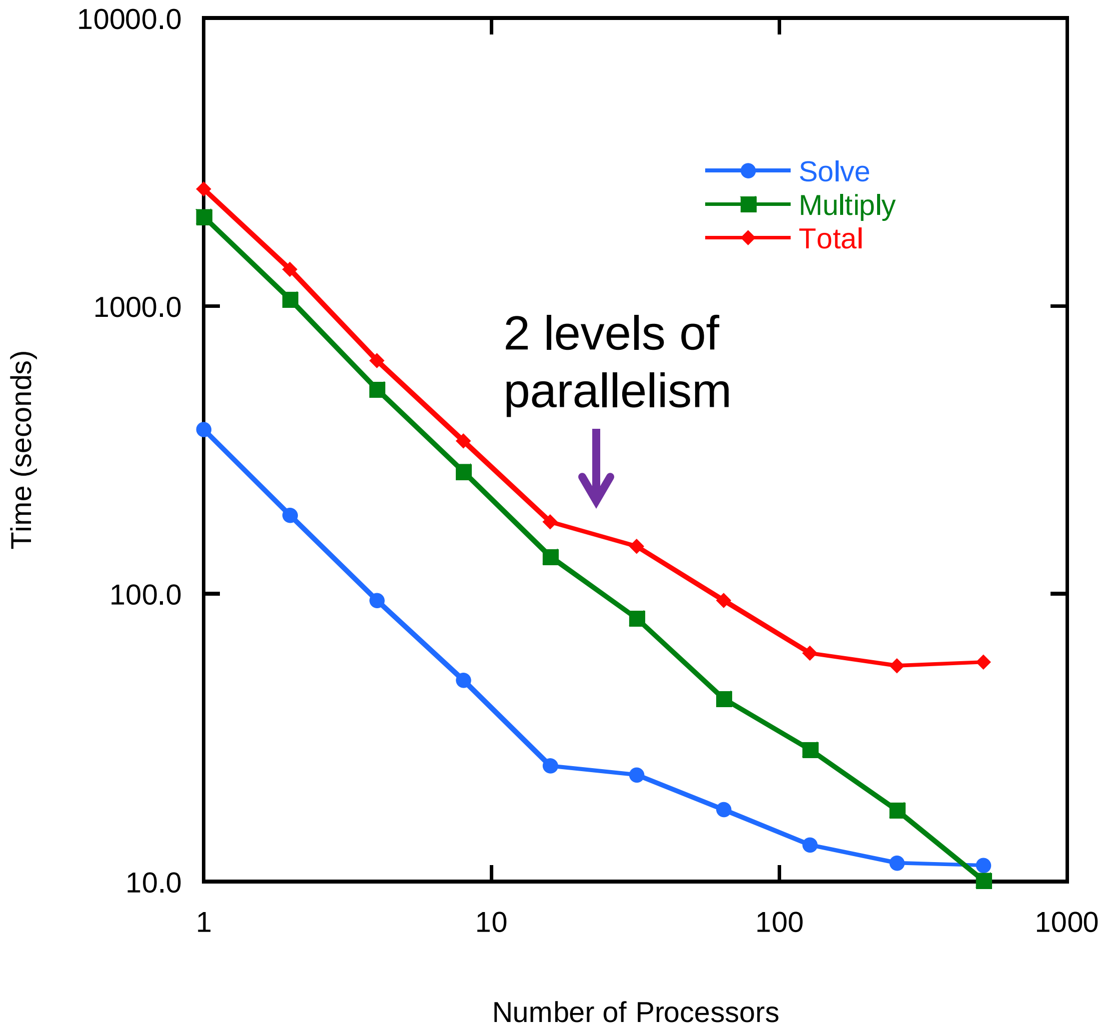


Dynamic Simulation



Simulation of
16351 bus
WECC
network

Dynamic Contingency Analysis



Simulation of 16 contingencies on 16351 bus WECC network

Conclusions

- A flexible framework for developing power grid applications that run on advanced computer architectures has been developed
- The framework supports most of the basic data structures and data manipulations common to many power grid applications
- Several power grid applications have been developed within the framework and show scaling behavior on multiple processors
- Documenation and downloads for GridPACK™ are available at https://gridpack.org

Acknowledgments

- This work is supported by the U.S. Department of Energy (DOE) through its Advanced Grid Modeling Program.
- Computing resources were provided by Pacific Northwest National Laboratory through its PNNL Institutional Computing prorgram

- GridPACK™ is available for download at https://gridpack.org