Parallel Discrete Event Simulation (PDES) at ORNL

Presented by

Kalyan S. Perumalla, Ph.D.
Modeling & Simulation Group
Computational Sciences & Engineering
PDES: Selected application areas

- **Network simulation**
  - Internet protocols, security, P2P designs, ...

- **Traffic simulation**
  - Emergency planning/response, environmental policy analysis, urban planning, ...

- **Social dynamics simulation**
  - Operations planning, foreign policy, marketing, ...

- **Sensor simulations**
  - Wide area monitoring, situational awareness, border surveillance, ...

- **Organization simulations**
  - Command and control, business processes, ...

Emergencies

Global and local events

Current and future defense systems

Protection and awareness systems
High-performance PDES kernel requirements

- **Global time synchronization**
  - Total time-stamped ordering of events
  - Paramount for accuracy

- **Fast synchronization**
  - Scalable, application-independent, time-advance mechanisms
  - Critical for real-time and as-fast-as-possible execution

- **Support for fine-grained events**
  - Minimal overhead relative to event processing times
  - Application computation is typically only 5 µs to 50 µs per event

- **Conservative, optimistic, and mixed modes**
  - Need support for the principal synchronization approaches
  - Useful to choose mode on per-entity basis at initialization
  - Desirable to vary mode dynamically during simulation

- **General-purpose API**
  - Reusable across multiple applications
  - Accommodates multiple techniques
    - Lookahead, state saving, reverse computation, multicast, etc.
µsik—unique PDES “micro-kernel”

Unique mixed-mode kernel
- The only scalable mixed-mode kernel in the world
- Supports conservative, optimistic, and mixed modes in a single kernel

Used in a variety of applications
- DES-based vehicular traffic models
- DES-based plasma physics models
- DES-based neurological models
- Largest Internet simulations

Some recent results of fine-grained PDES benchmark (phold)
- Among the largest/fastest scalability results in parallel discrete event simulation
μsik scaled to more than $10^4$ processors

- Some recent results of fine-grained PDES benchmark
  - On Blue Gene Watson (BGW) at IBM TJ Watson Research Center
  - Well-known PHOLD benchmark, with 1 million logical processes, 10 million pucks
- The largest and fastest scalability results in PDES recorded to date
µsik micro-kernel internals

**Micro-kernel**

- **Pc**: Earliest committable time stamp
- **EPTS Q**: Processable
- **Pe**: Earliest emittable time stamp

**User LPs**

- **LP**: Logical process
- **FEL → t**: Future event list
- **PEL → t**: Processed event list
- **LVT**: Local virtual time

**Kernel LPs**

- **KP**: Kernel process

When update kernel Qs?
- New LP added or deleted
- LP executes an event
- LP receives an event

LP = Logical process
KP = Kernel process
ECTS = Earliest committable time stamp
EPTS = Earliest processable time stamp
EETS = Earliest emittable time stamp
PEL = Processed event list
FEL = Future event list
LVT = Local virtual time
libSynk: μsik’s synchronization core
\textbf{\(\mu\text{sik\) micro-kernel capabilities}}

- \(\mu\text{sik}\) is currently able to support the following:
  - Lookahead-based conservative and/or optimistic execution
  - Reverse computation-based optimistic execution
  - Checkpointing-based optimistic execution
  - Resilient optimistic execution (zero rollbacks)
    - Constrained, out-of-order execution
    - Preemptive event processing
  - Any combinations of the above
  - Automated, network-throttled flow control
  - User-level event retraction
  - Process-specific limits to optimism
  - Dynamic process addition/deletion
  - Shared and/or distributed memory execution
  - Process-oriented views

- It accommodates addition of the following:
  - Synchronized multicast
  - Optimistic dynamic memory allocation
  - Automated load-balancing
SensorNet: Parallel simulation/immersive test-bed

- Seamless integrated testbed to incorporate a variety of important simulations, stimulations, and live devices
- Achieves unified capabilities and significant fidelity for test and evaluation of CB sensor device-based designs, concepts, and operations
SensorNet: Simulation-based analysis for plume tracking

- Environmental phenomenon exhibits high variability.
- Phenomenon drives the sensor network’s computation and communication.
- Trace gathered at base station of sensed phenomenon reflects high variability.
- Communication effects induce unpredictable gaps in series.
- Accurate, integrated simulation of phenomenon and communication captures complex interdependencies.
SCATTER: Ultra-scale PDES-based mobility simulations

- Scalable tool for transportation and energy/event/emergency research
- Regional scale: multiple states
  - $10^6$–$10^7$ intersections
- Current tool capabilities
  - At most $10^4$ intersections
- Faster than real time is very useful

Our approach: SCATTER
- DES models
  - vs time-stepped
- Parallel execution
  - vs sequential
- Scalability to high-performance computing
  - $10^2$–$10^3$ CPUs
- Important behaviors
  - kinetic + non-kinetic

Network flow methods
- OREMS
- CORSIM
- MITSIM
- TRANSIMS

Fidelity
- Good for rough estimates of evacuation delay, ...
- Good for emissions estimates, traffic analysis, ...

Speed
- Faster
- Slower

Higher accuracy
- Lower accuracy
SCATTER: Benchmark performance

**Event processing speed**

- **Nodes = 9**
- **Nodes = 1089**

**Very low event processing overhead (ms)!**

**Real time/simulated time**

- **Nodes = 9**
- **Nodes = 1089**

**Significantly faster than real time with 1 million vehicles!**

**Speedup over real-time**

**Parallel Speedup**

- **Significant speedup with parallel execution!**
Contact

Kalyan S. Perumalla
Modeling & Simulation Group
Computational Sciences & Engineering
(865) 241-1315
perumallaks@ornl.gov