GEANT4
A SIMULATION TOOLKIT

Version 10.7

Multithreading

John Apostolakis (CERN)
Geant4 Beginners Course

Slides from Makoto Asai (SLAC) – with small changes

Outline:

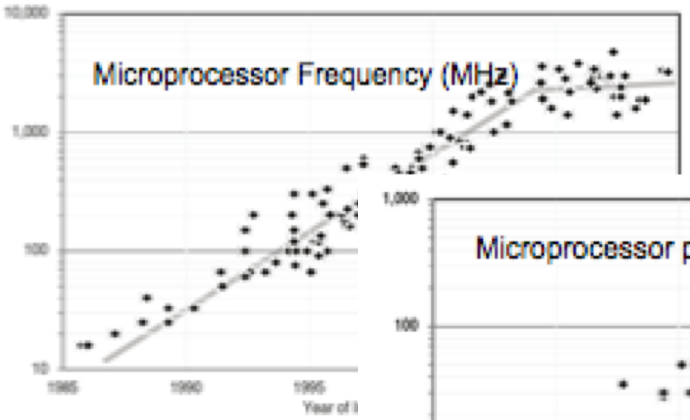
- Introduction
- Multithreading in Geant4 : the basics
- UI commands for multithreading

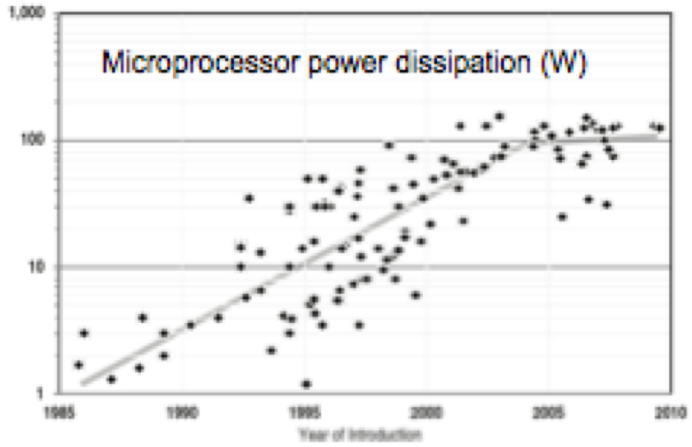
GEANT4
A SIMULATION TOOLKIT

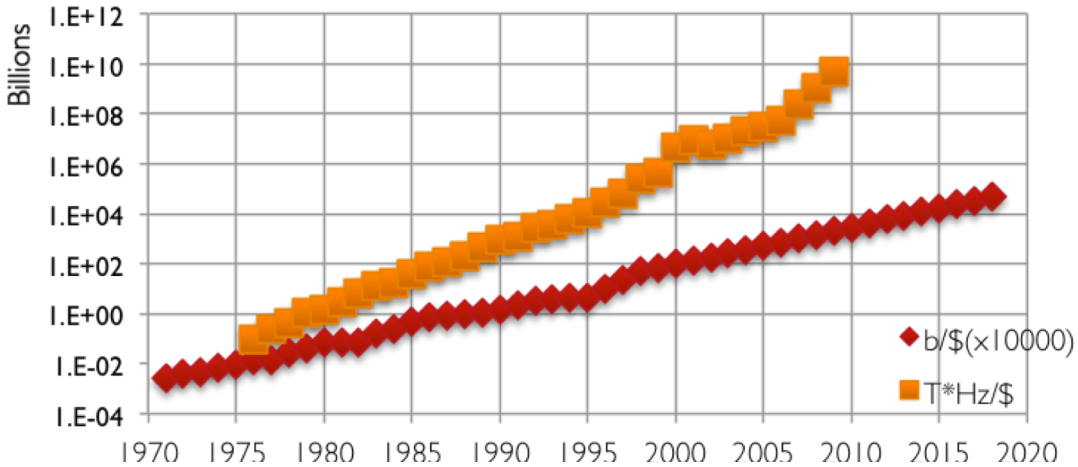
Version 10.7

Introduction

The challenges of many-core era







- Higher frequency of CPU **increase power consumption**
- Reached plateau around 2005
- No more increase in CPU frequency
- However number of transistors per chip continues to grow
- Multi/Many-core era
- Note: quantity memory you can buy with same $ scales slower

- **Expect:**
- Many core (double/2yrs?)
- Single core performance increases slowly
- Less memory/core
- New software models need to take these into account: increase parallelism

CPU Clock Frequecy and usage: The Future of Computing Performance: Game Over or Next Level?
DRAM cost: Data from 1971-2000: VLSI Research Inc. Data from 2001-2002: ITRS, 2002 Update, Table 7a, Cost-Near-Term Years, p. 172. Data from 2003-2018: ITRS, 2004 Update, Tables 7a and 7b, Cost-Near-Term Years, pp. 20-21.
CPU cost: Data from 1976-1999: E. R. Berndt, E. R. Dulberger, and N. J. Rappaport, "Price and Quality of Desktop and Mobile Personal Computers: A Quarter Century of History," July 17, 2000, ;Data from 2001-2016: ITRS, 2002 Update, On-Chip Local Clock in Table 4c: Performance and Package Chips: Frequency On-Chip Wiring Levels -- Near-Term Years, p. 167. ;
Average transistor price: Intel and Dataquest reports (December 2002), see Gordon E. Moore, "Our Revolution,"

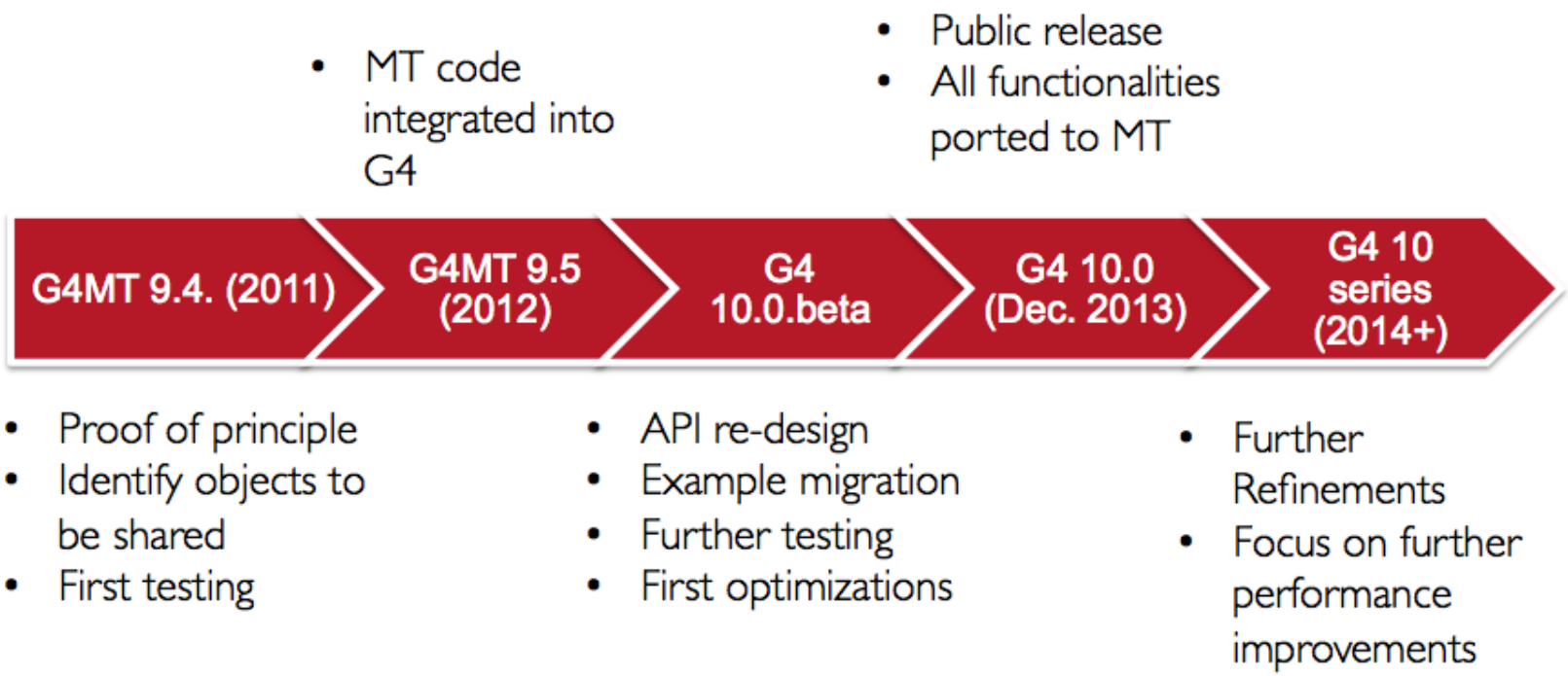
In Brief

- Modern CPU architectures: need to introduce **parallelism**
- Memory and its access will limit number of concurrent processes running on single chip
- Solution: add parallelism **in the application code**

- Geant4 needs back-compatibility with user code and **simple approach** (physicists != computer scientists)
- **Events are independent**: each event can be simulated separately

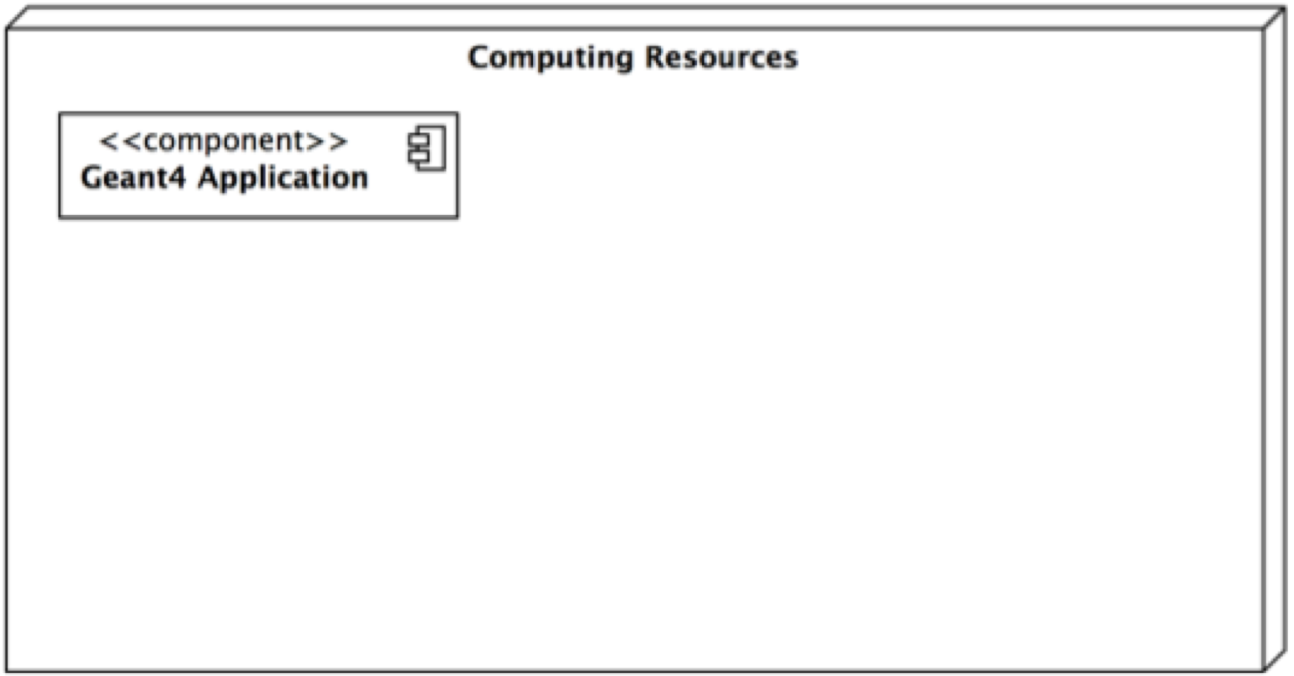
- Multi-threading for event level parallelism was the natural choice

Geant4 Multi Threading – history & capabilities



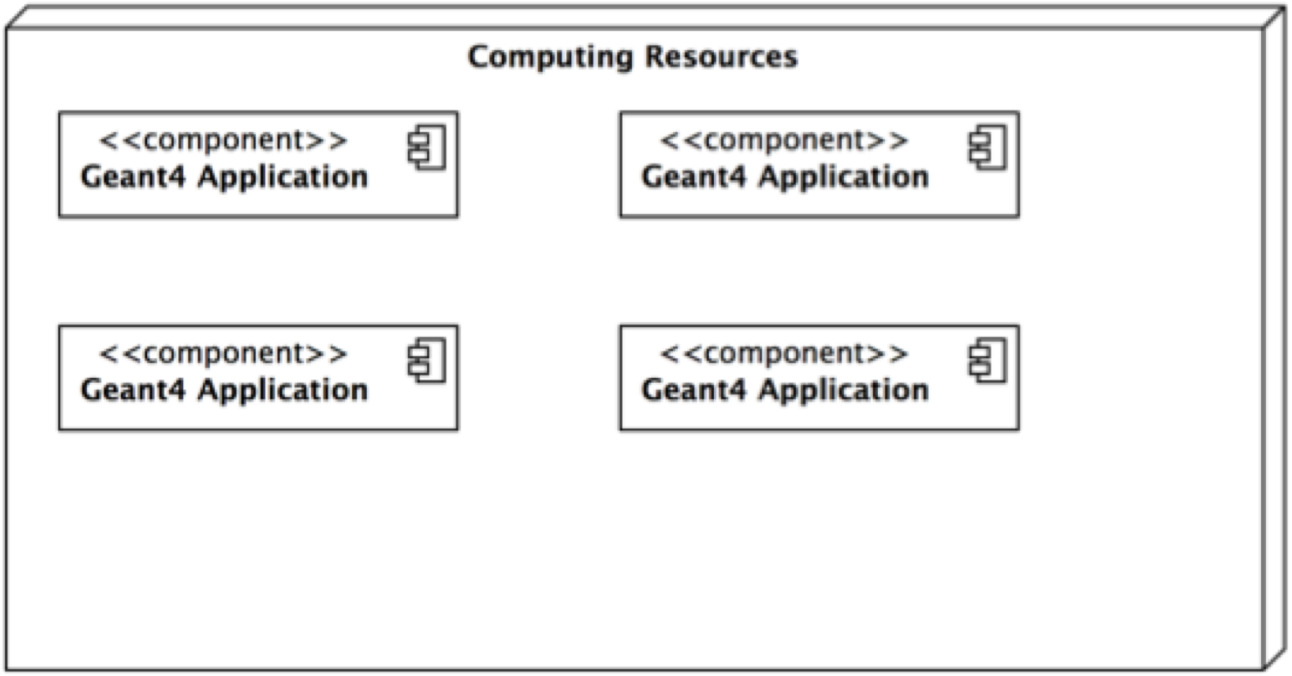
What is a thread?

Sequential application



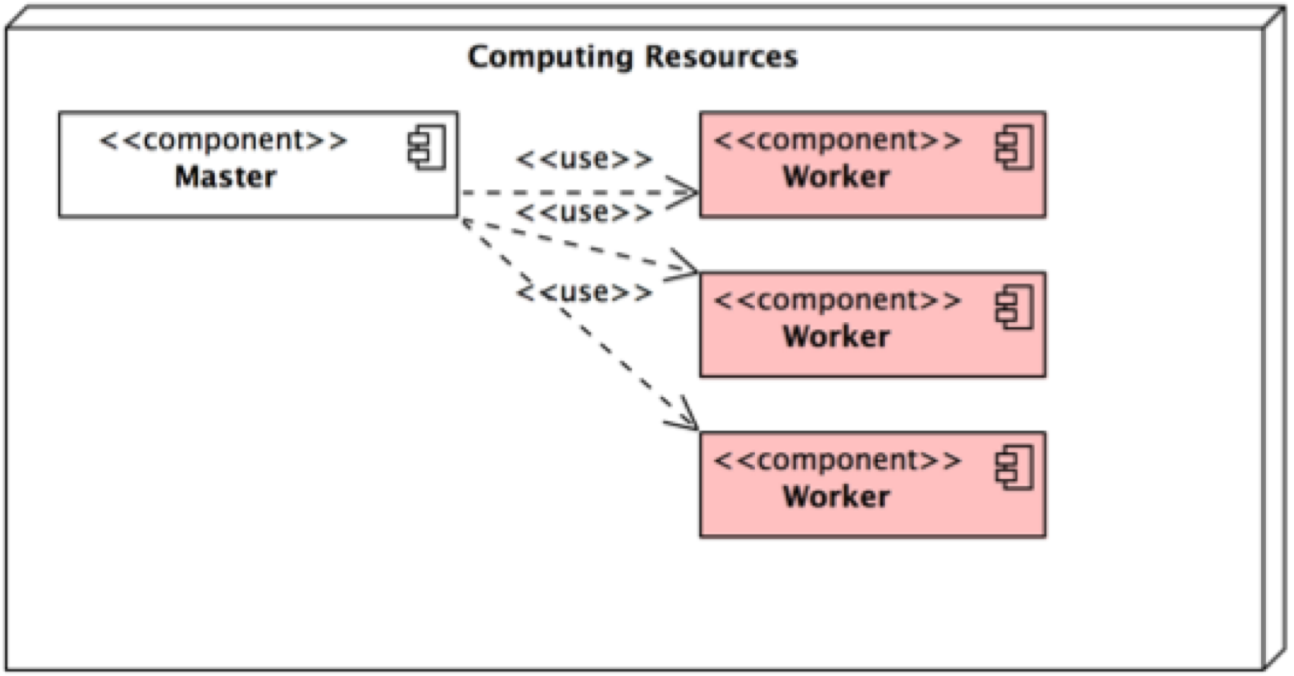
What is a thread?

Sequential application: start N (cores/CPUs) copies of application if fits in memory



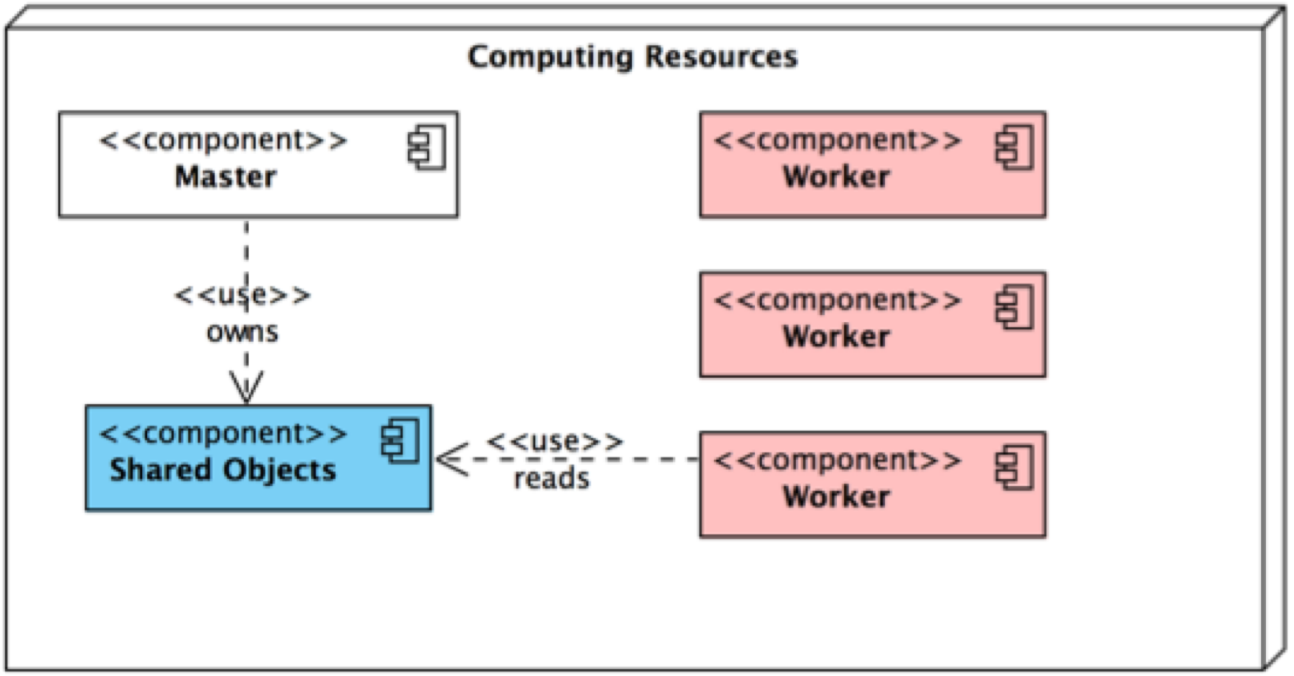
What is a thread?

MT Application: single application starts threads. For G4: application (master) controls workers that do simulation, no memory sharing now, each worker is a copy of the application



What is a thread?

Memory reduction: introduce shared objects, memory of N threads is less than memory used by N copies of application

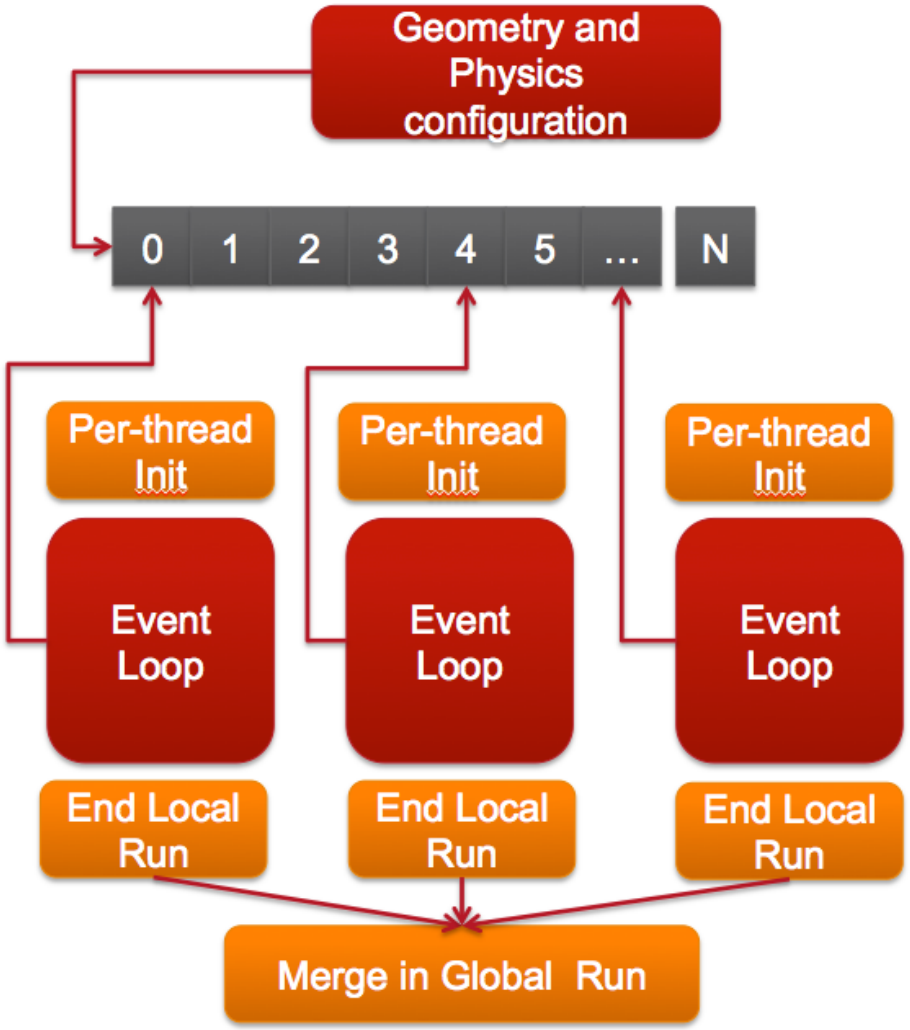


GEANT4
A SIMULATION TOOLKIT

Version 10.7

Multi-threading in Geant4: the basics

General Design



Per-event seeds pre-prepared in a "queue"

Threads compete for next event to be processes

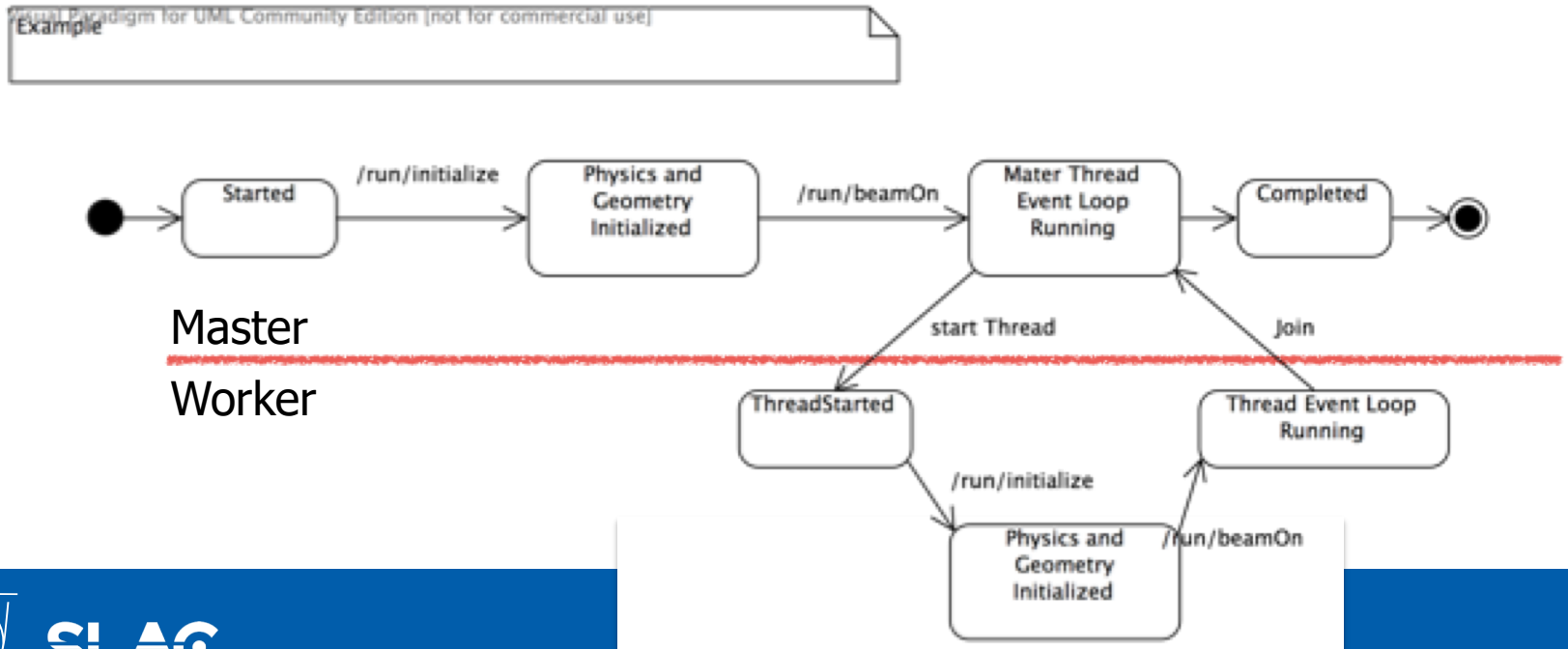
Command line scoring and G4tools automatically merge results from threads

Simplified Master / Worker Model

- A G4 (with MT) application can be seen as simple finite state machine

Simplified Master / Worker Model

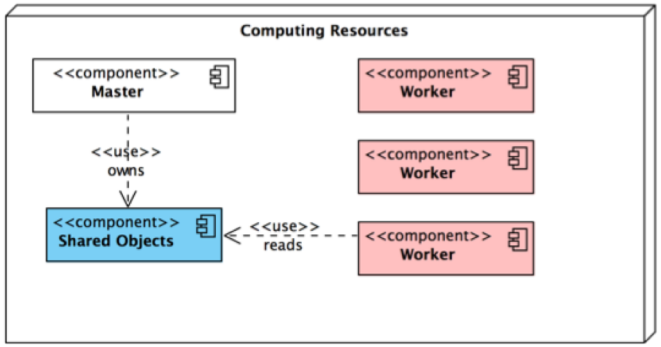
- A G4 (with MT) application can be seen as simple finite state machine
- Threads do not exists before first /run/beamOn
- When master starts the first run spawns threads and distribute work



13

Shared Vs Thread-local

- To reduce memory footprint threads must share at least part of the objects
- **General rule in G4: threads can share whatever is invariant during the event loop** (e.g. threads do not change these objects while processing events, these are used "read-only")
  - Geometry definition
  - Electromagnetic physics tables

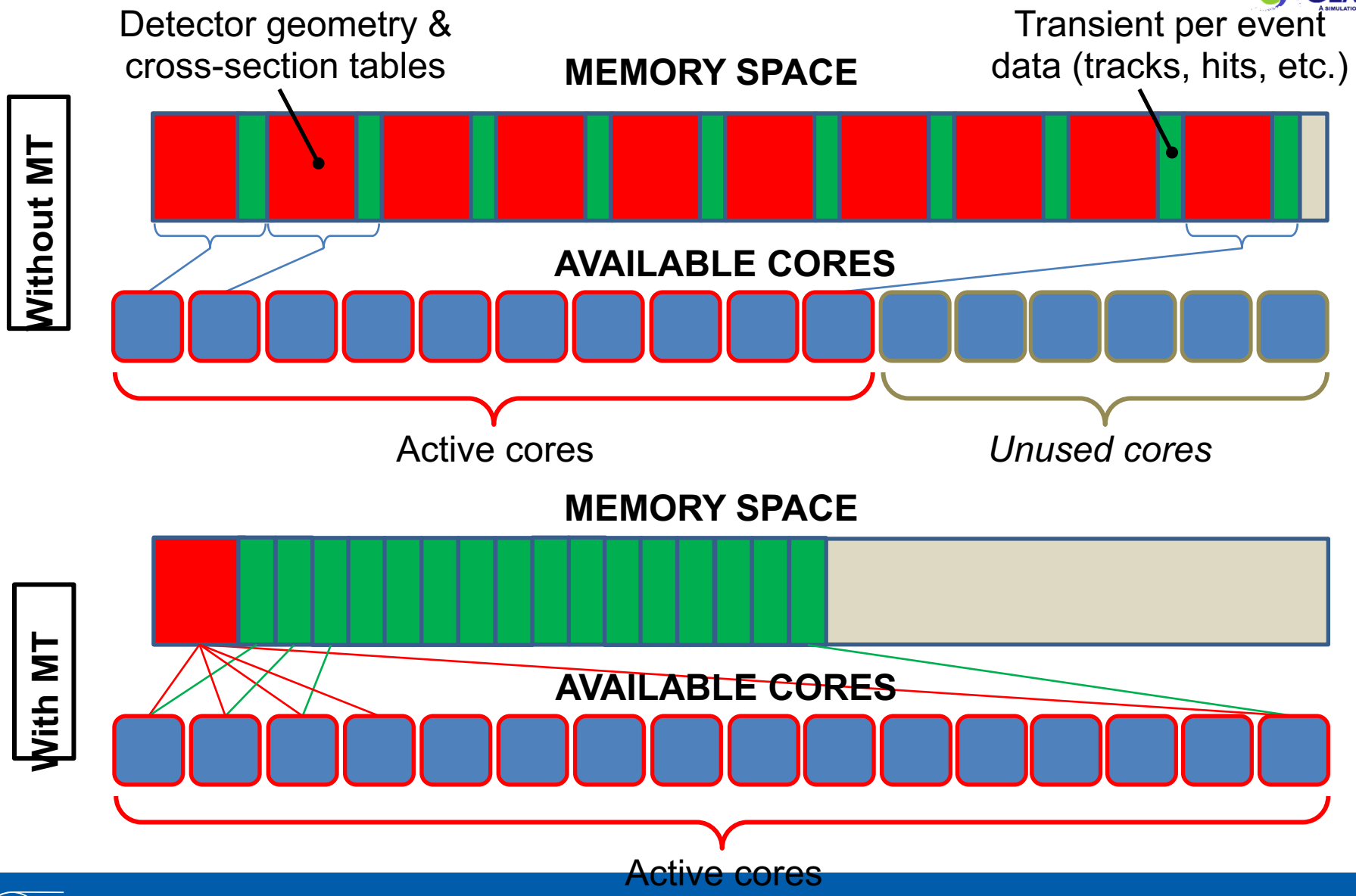


Shared ? Private?

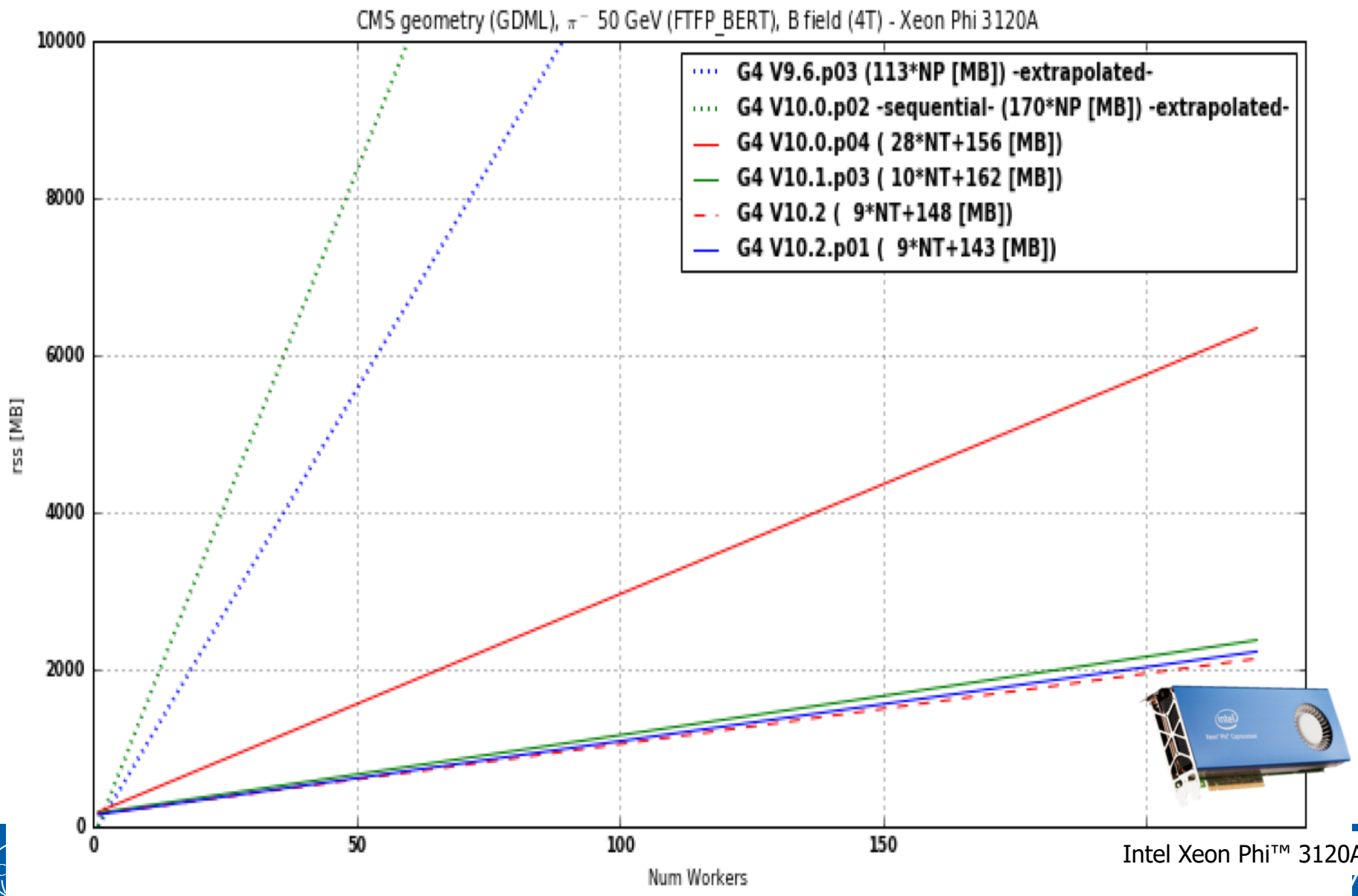
- In the multi-threaded mode
  - data that is stable during the event loop is shared among threads, while
  - data that is transient during the event loop is thread-local.

- Shared by all threads
  : stable during the event loop
  - Geometry
  - Particle definition
  - Cross-section tables
  - User-initialization classes

- Thread-local
  : dynamically changing for every event/track/step
  - All transient objects such as run, event, track, step, trajectory, hit, etc.
  - Physics processes
  - Sensitive detectors
  - User-action classes

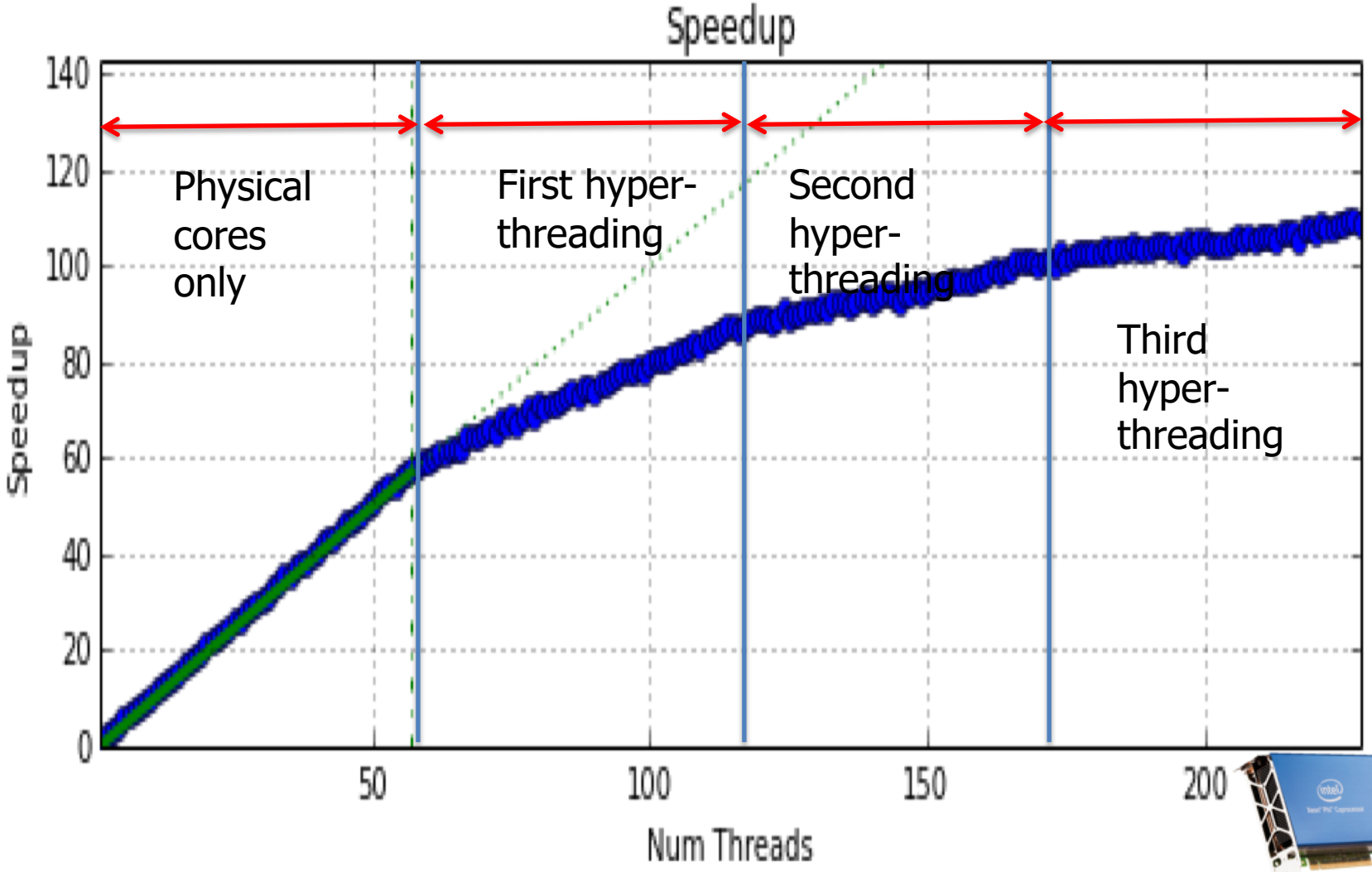

Detector geometry &
cross-section tables
MEMORY SPACE
Transient per event
data (tracks, hits, etc.)
Without MT
AVAILABLE CORES
Active cores
Unused cores
MEMORY SPACE
With MT
AVAILABLE CORES
Active cores

Memory consumption on Intel Xeon Phi



Intel Xeon Phi™ 3120A

Scalability on Intel Xeon Phi

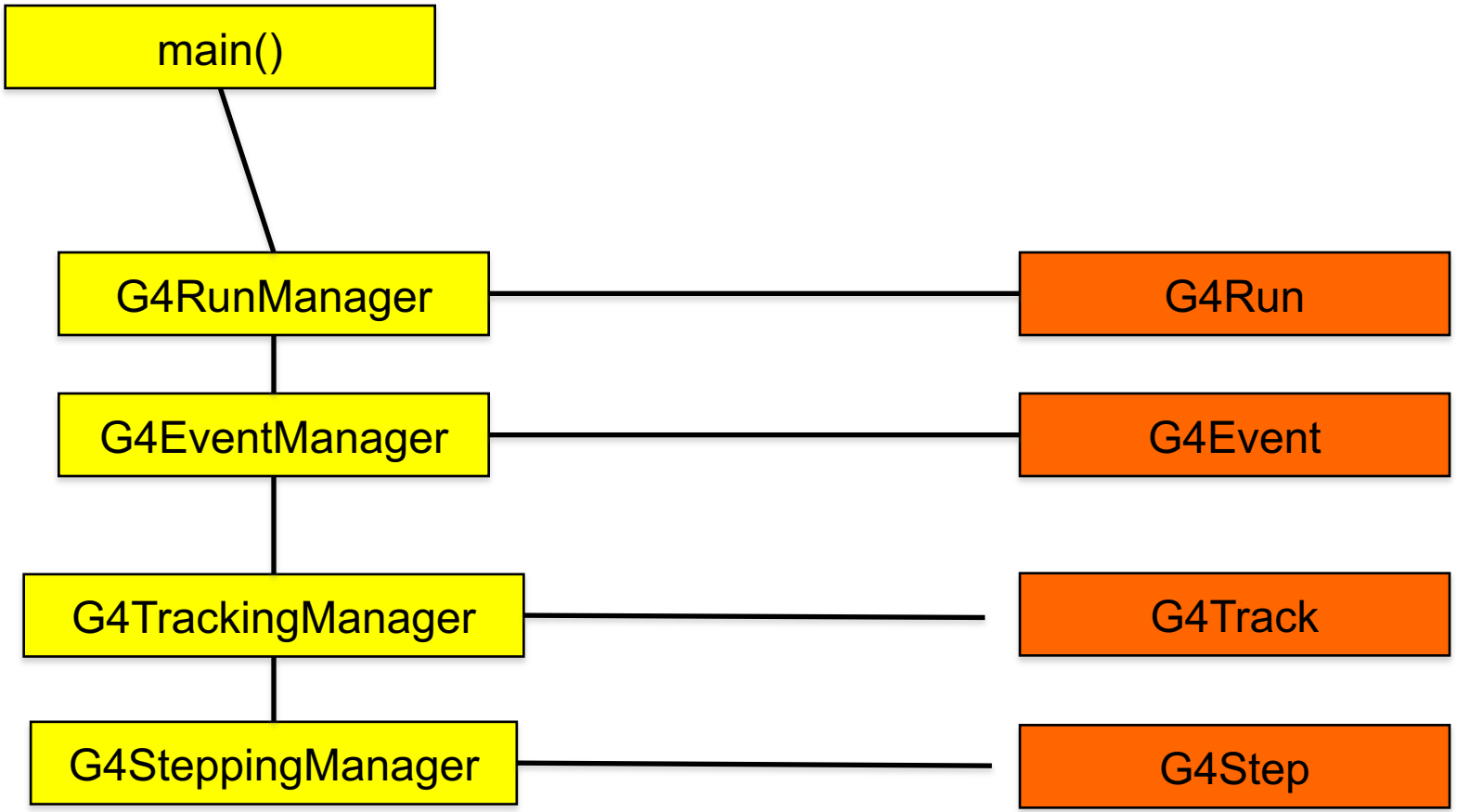


Intel Xeon Phi™ 3120A

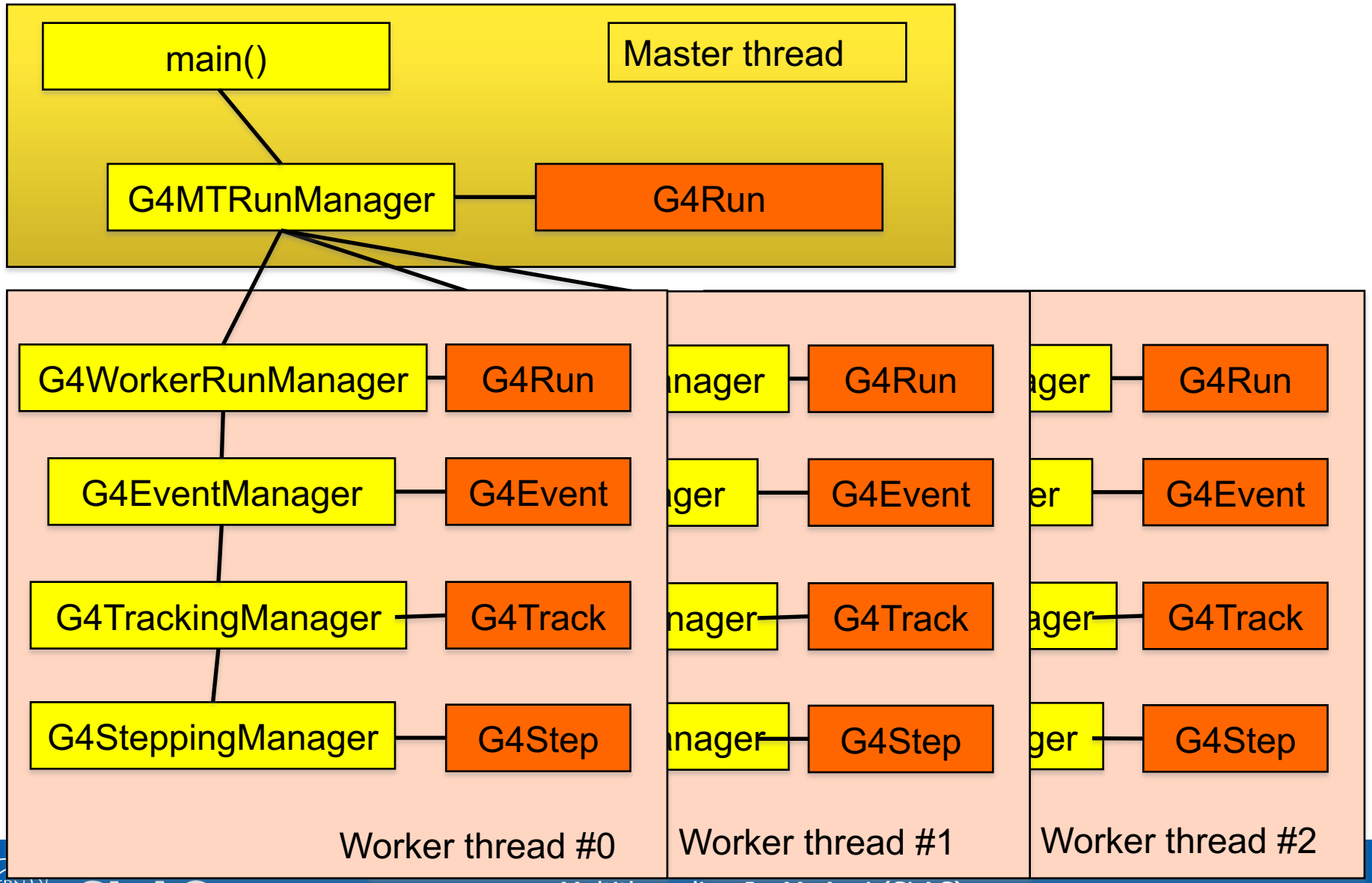
Shared ? Thread-local?

- The geometry and physics tables are shared.
- The event, track, step, trajectory, hits, etc., as well as several Geant4 manager classes (EventManager, TrackingManager, SteppingManager, TransportationManager, FieldManager, SensitiveDetectorManager) and Navigator are thread-local.
- Among the user classes, the initialization classes (G4VUserDetectorConstruction, G4VUserPhysicsList and the new G4VUserActionInitialization) are shared, whereas all user action classes and sensitive detector classes are thread-local.
  - It is not straightforward (and thus not recommended) to access a thread-local object from a shared class object, e.g. from detector construction to stepping action.
  - Please note that thread-local objects are instantiated and initialized at the first *BeamOn*.
- To avoid potential errors, try to keep in mind which classes are shared and which classes are thread-local.

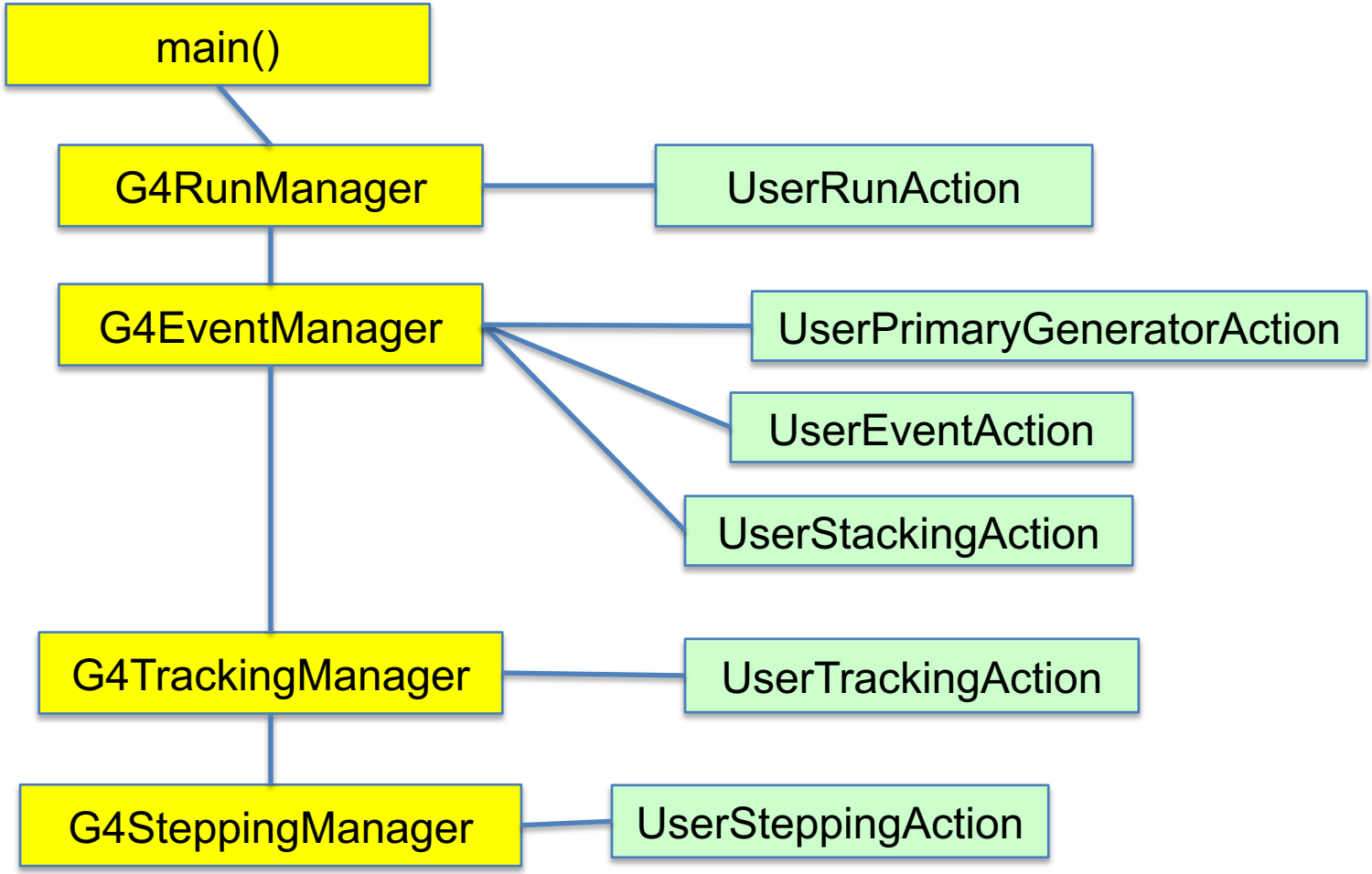
Sequential mode



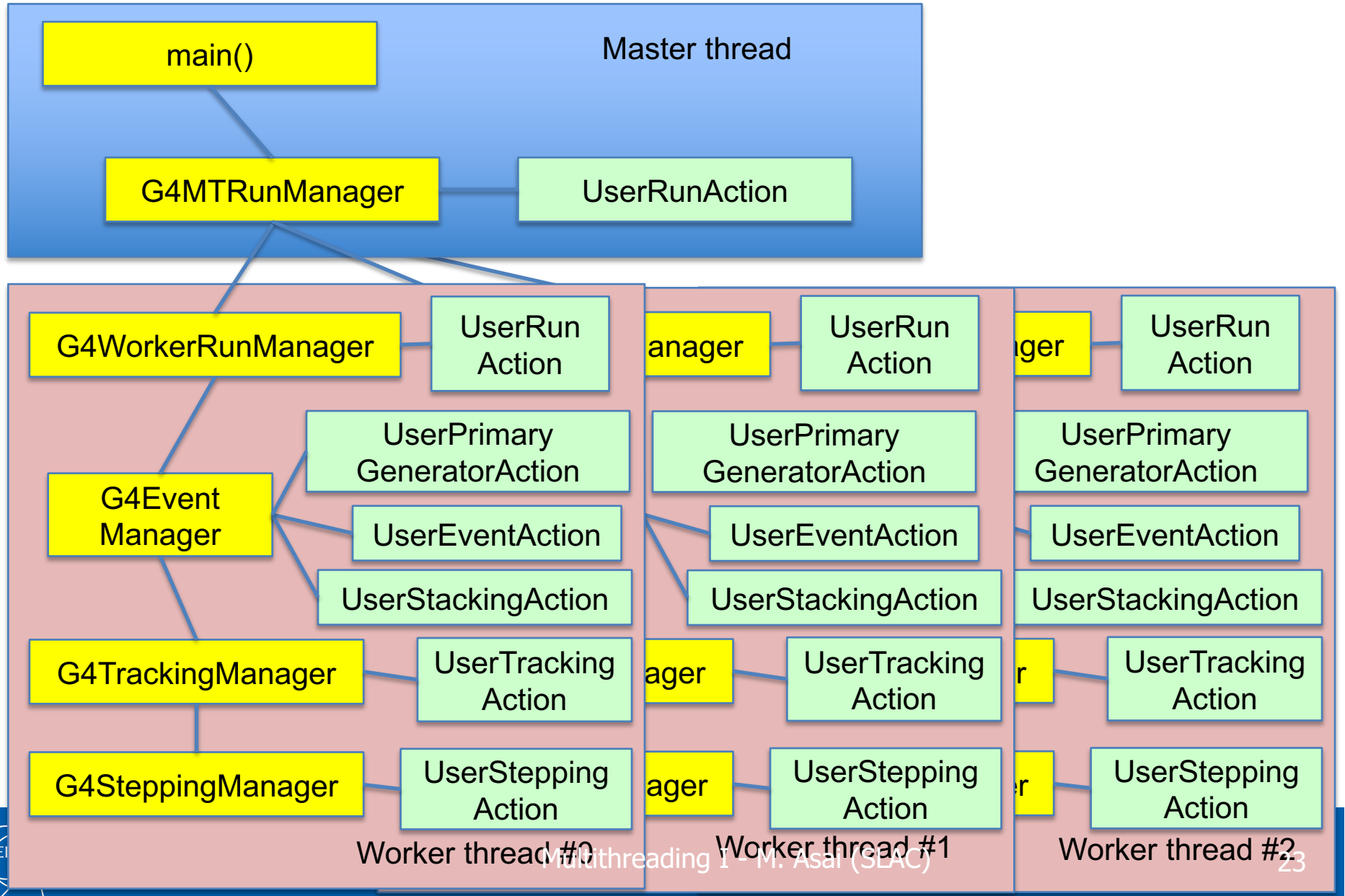
Multi-threaded mode



Sequential mode



Multi-threaded mode



GEANT4
A SIMULATION TOOLKIT

Version 10.7

UI commands for multithreading

Number of worker threads

- You can specify the number of worker threads.
  - They do not include master thread or visualization thread.
- Shell environment variable *G4FORCENUMBEROFTHREADS*. This will overwrite the following alternative settings. *G4FORCENUMBEROFTHREADS* can be an integer or a keyword "max". If "max" is specified, Geant4 uses all threads of the machine including all hyper threads.
- UI command */run/numberOfThreads, /run/useMaximumLogicalCores*
  - This UI command has to be issued at *PreInit>* state.
- *G4RunManager::SetNumberOfThreads(G4int)*
  - This method must be invoked prior to *G4RunManager::Initialize()*.

- UI command */run/pinAffinity*
  - Locks worker threads to specific logical cores.

/run/eventModulo <N> <seedOnce>

- Set the event modulo for dispatching events to worker threads
  - Each worker thread is tasked to simulate <N> events and then comes back to G4MTRunManager for next set.
- If it is set to zero (default value), N is roughly given by this.
  - N = int(sqrt(number_of_events / number_of_threads))
- The value N may affect on the computing performance in particular, if N is too small compared to the total number of events.
- The second parameter <seedOnce> specifies how frequent each worker thread is seeded by the random number sequence centrally managed by the master G4MTRunManager.
  - If <seedOnce> is set to 0 (default), seeds that are centrally managed by G4MTRunManager are set for every event of every worker thread. This option guarantees event reproducibility regardless of number of threads.
  - If <seedOnce> is set to 1, seeds are set only once for the first event of each run of each worker thread. Event reproducibility is guaranteed only if the same number of worker threads are used. On the other hand, this option offers better computing performance in particular for applications with relatively small primary particle energy and large number of events.

UI commands for cout/cerr

- /control/cout/useBuffer <*flag*>
  - Store G4cout and/or G4cerr stream to a buffer so that output of each thread is grouped.
  - The buffered text will be printed out on a screen for each thread at a time at the end of the job or at the time the user changes the destination to a file.
- /control/cout/ignoreThreadsExcept <*threadID*>
  - Omit output from threads except the one from the specified thread.
  - If *threadID* is greater than the actual number of threads, no output is shown from worker threads.
  - To reset, use -1 as *threadID*.
- /control/cout/prefixString <*prefix*>
  - In case G4cout and/or G4cerr are not buffered, output of all threads are displayed on the screen simultaneously.
  - With this command, the user may specify a prefix for each output line which is supplemented by the thread ID. By default it is “G4MT”
- /control/cout/setCoutFile <*fileName*> <*ifAppend*>
  /control/cout/setCerrFile <*fileName*> <*ifAppend*>
  - Send *G4cout/G4cerr* stream to a file dedicated to each thread. The file name has "G4W_n_" prefix where *n* represents the thread ID.
  - File name may be changes for each run. If *ifAppend* parameter is false, the file is overwritten when exactly the same file has already existed.
  - To change the *G4cout/G4cerr* destination back to the screen, specify the special keyword "**Screen**" as the file name.

LATEST DEVELOPMENTS

Moving from threads to tasks – upcoming in release 10.7

- Geant4 10.7 (December 2020)
  - New ‘task-oriented’ capability similar to frameworks of LHC experiments
  - Includes a native C++ implementation of the ‘task model’
  - Includes an (Intel) Thread Building Block ‘TBB task mode’ – the Geant4 installation must find & use TBB, (by configuring cmake with -DGEANT4_USE_TBB=ON)
- There is now a variety of RunManagers
  - Sequential (G4RunManager)
  - ‘Old-style’ Multi-threading (G4MTRunManager)
  - G4TaskRunManager in ‘native’ mode
  - G4TaskRunManager in TBB mode
- A new class G4RunManagerFactory can be used to create any of these:

```
// [Option #1] enum class G4RunManagerType: Default, Serial, MT, Tasking, TBB
auto* runMgr = G4RunManagerFactory::CreateRunManager(
      G4RunManagerType::Default, 4);
// [Option #2] string:  “default”, “serial”, “mt”, “task”, “tbb”
auto* runMgr = G4RunManagerFactory::CreateRunManager( "default", 4);
```