VGP393 – Week 3

- Agenda:
  - Finding Concurrency
    - Program decompositions
    - Dependency analysis
    - Design evaluation
  - Quiz #1
  - Assignment #1 due
  - Assignment #2 starts

30-July-2008

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Finding Concurrency

- Parallel programming is about *finding* and *exploiting* concurrency

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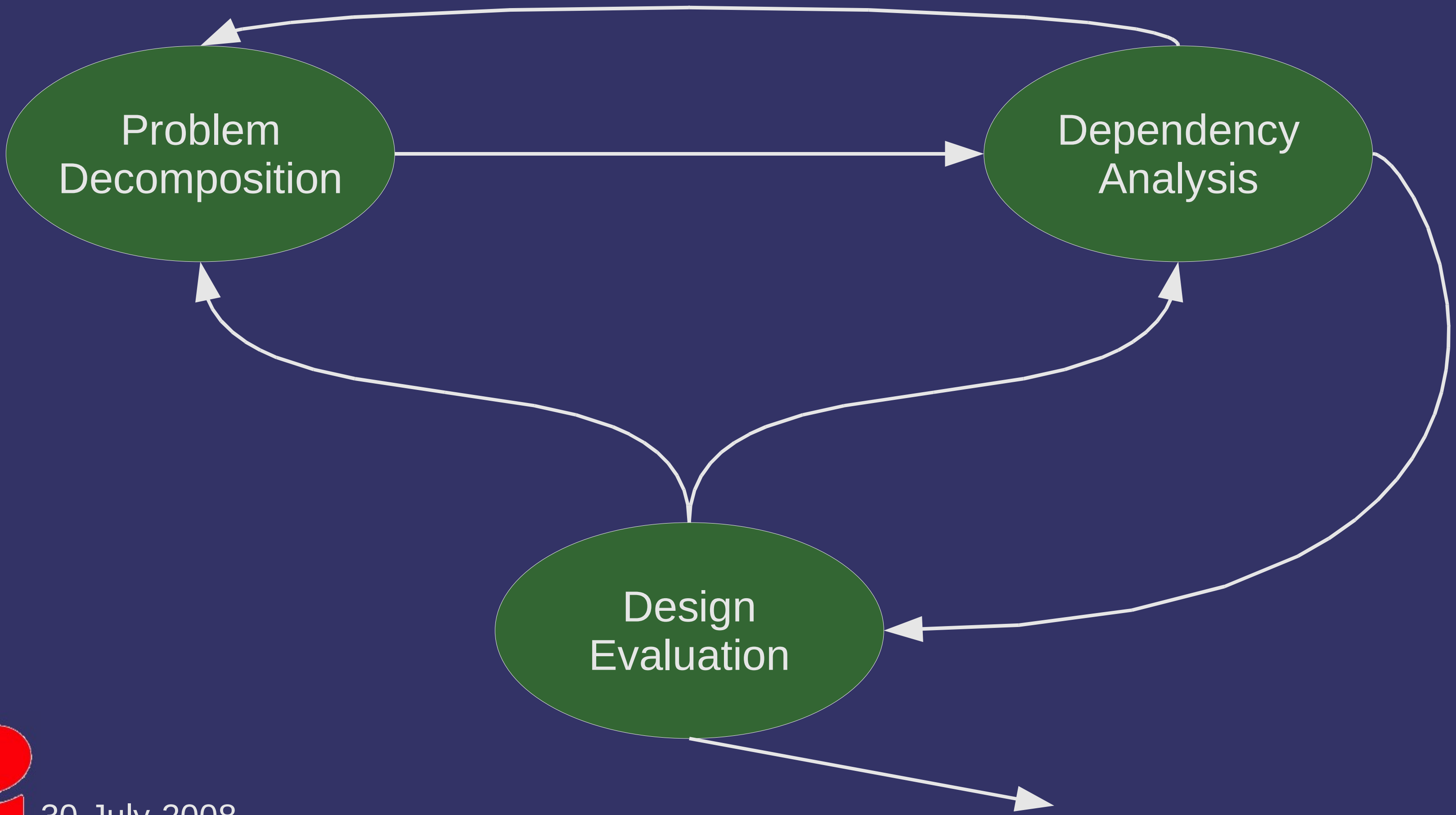
Problem Decomposition

Dependency Analysis

Design Evaluation

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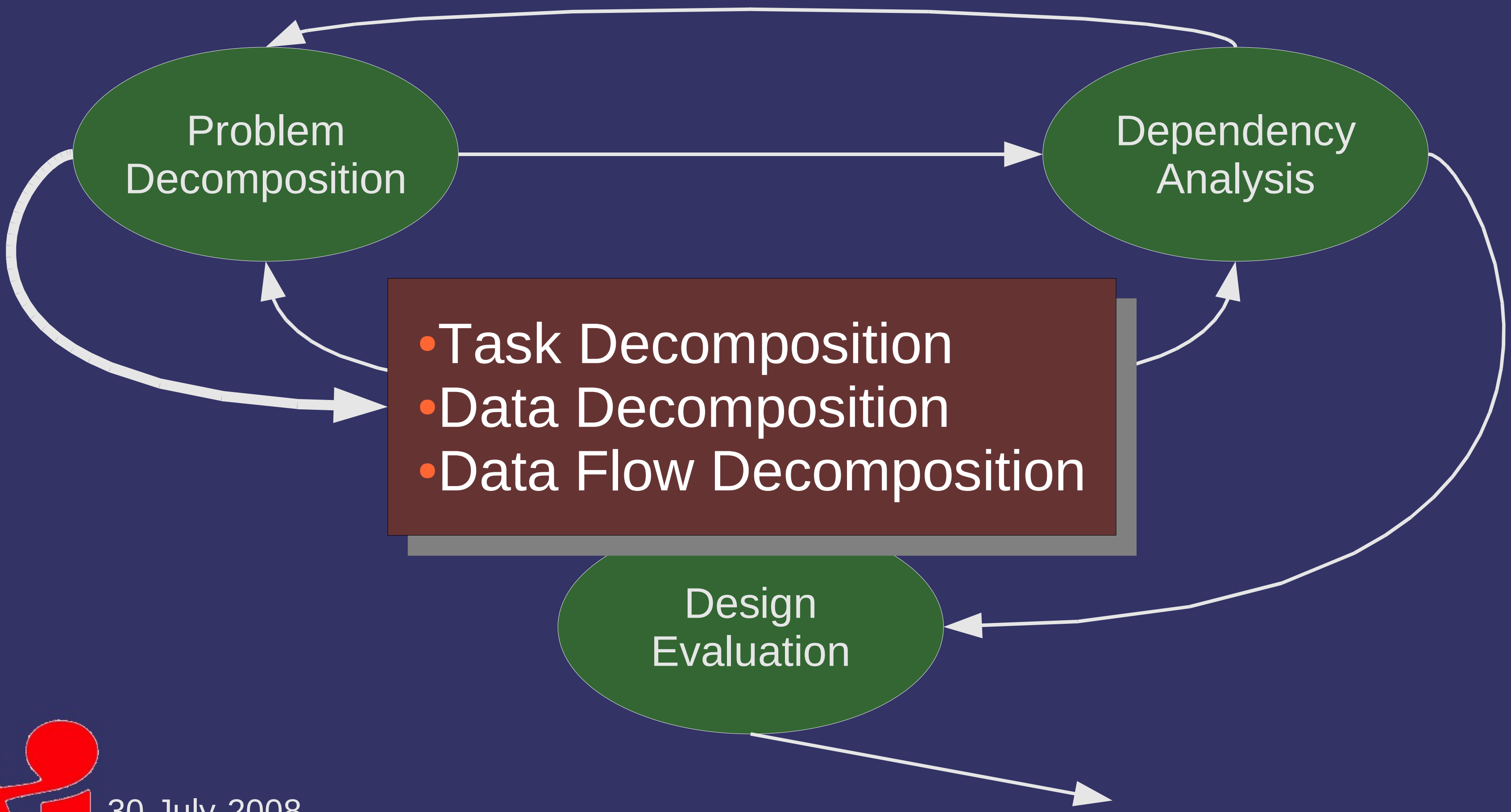

Problem Decomposition

Dependency Analysis

- Task Decomposition
- Data Decomposition
- Data Flow Decomposition

Design Evaluation

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Problem Decompositions

- Must decompose the problem into elements that can execute in parallel
- Decomposition occurs along two primary axes and one secondary axis
  - *Task decomposition* views the problem as a sequence of *tasks* that can be executed concurrently
  - *Data decomposition* views the data problem as separate chunks that can be evaluated concurrently
  - *Data flow decomposition* looks at how data flows through the program as the problem is solved

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Driving Forces

- Three forces drive all decompositions:
  - Flexibility – Is the design flexible enough to be adapted to changes in requirements?
    - Usually changes in problem size or changes in target system
  - Efficiency – Does the design scale to *at least* the number of processors in the target system?
    - Efficiency for one target system may come at the cost of flexibility to other systems
  - Simplicity – Can the program design be understood, debugged, and maintained?
    - Simplicity can come at a cost to efficiency

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Task Decomposition

- Look at the problem as a collection of tasks
  - Look at the individual steps required to solve the problem
  - Determine whether or not these steps are independent
- Find as many tasks as possible
  - Individual function calls
  - Iterations of a loop
  - Updates to portions of large data structures

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Task Decomposition

- Evaluate the design...
  - Flexibility – Be flexible in the number of tasks
    - Parametrize the number and size of tasks at run-time
  - Efficiency – Two possibly opposing goals:
    - Tasks should be large enough to outweigh management overhead
    - Should be enough tasks to keep all PEs busy all the time
  - Simplicity – Tasks should be defined in such a way that debugging and maintenance are easy
    - Re-use code from sequential version of program

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Data Decomposition

- Works well if...
  - Problem focuses on the manipulation of a large data structure
  - The same or similar operations are performed on different parts of the structure in independent ways
- Focus on data structures that can be broken into chunks that can be operated on concurrently
  - Concurrency can be found in *array-based computations* by looking at updates to different segments of the array
  - Concurrent updates on *recursive data structures* can be performed on different subtrees, etc.

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Data Decomposition

- Evaluate the design...
  - Flexibility – Be flexible in the size and number of data chunks
    - *Granularity knobs* are parameters in the program that, at run-time, control the size and number of data chunks
    - Granularity has a major impact on the overhead required to manage dependencies between the chunks
    - Dependencies should scale at a slower rate than effort required to compute each chunk

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Data Decomposition

- Evaluate the design...
  - Efficiency – An efficient design should evenly map work to UEs and not create too much additional management work
    - Size of data chunks must be large enough to dominate the amount of work required to manage the dependencies
    - Mapping chunks to UEs must also be considered. If the mapping is poor, some PEs will have much more work to do than others
    - Cache and memory access (NUMA) issues are important for data that must be shared

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Data Decomposition

- Evaluate the design...
  - Simplicity – Complex data mappings are difficult to debug
    - Abstract data types to control the mapping of global data to task-local data are useful

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Data Flow Decomposition

- Look at how data flows from one task to another
  - Hybrid of task decomposition and data decomposition
- Key feature is that one task cannot begin until it receives data from another task
  - *Producer-consumer* problems are the classic example
  - Understand the nature of the dependency between tasks
    - Seek to minimize the delay caused by the dependency

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Finding Concurrency

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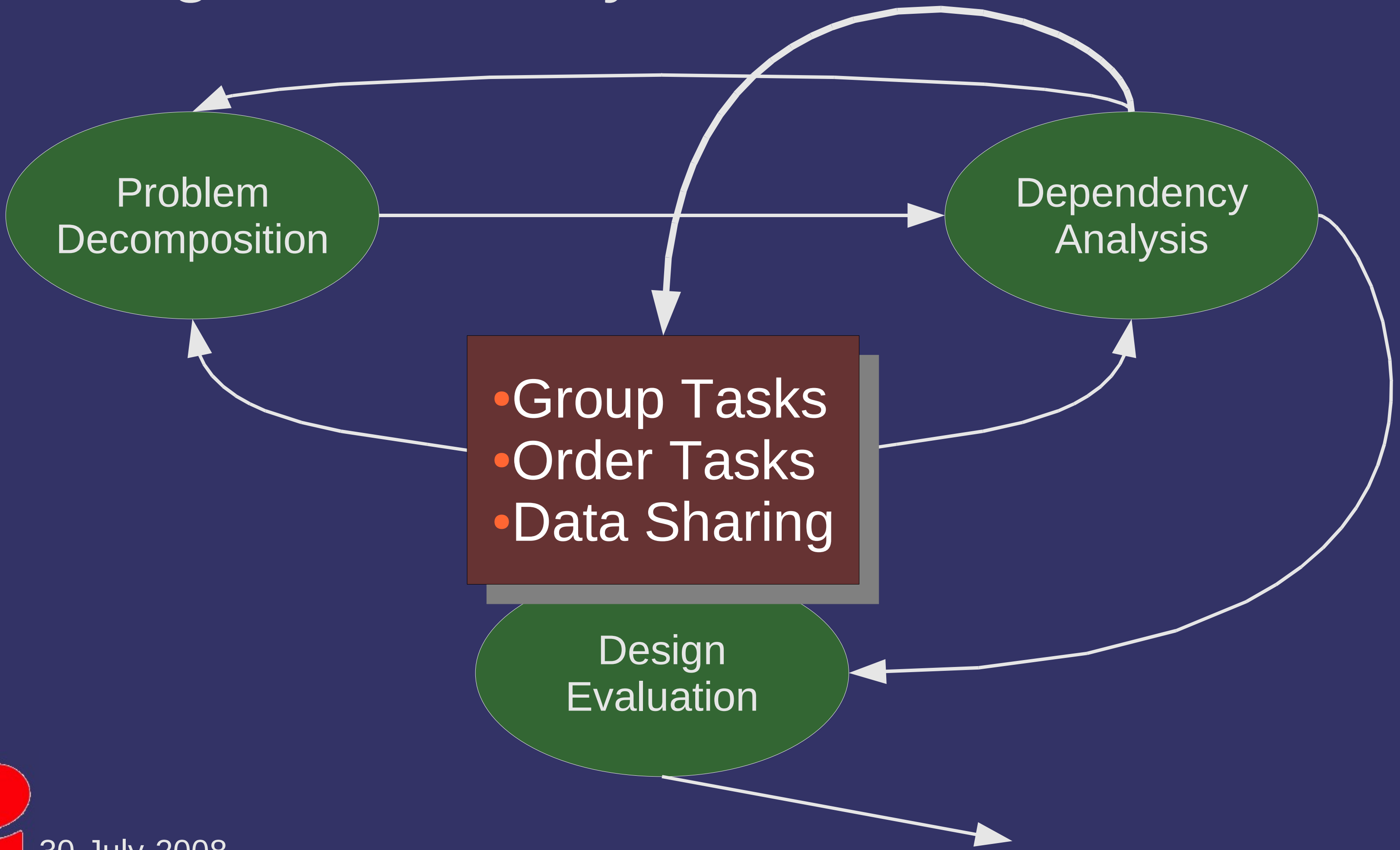

Problem Decomposition

Dependency Analysis

- Group Tasks
- Order Tasks
- Data Sharing

Design Evaluation

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Dependency Analysis

- Sometimes task decomposition generates sets of tasks that are entirely independent
    - These problems are often called *embarrassingly parallel*
- *Dependencies* are cases where the execution of one task affects the execution of another
    - *Data-sharing dependencies* can occur when tasks must share or exchange data during execution
    - *Ordering constraints* occur when tasks must execute in a certain order

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Dependency Analysis

- Several common ordering constraints:
  - Sequential (or data flow) dependency – One task needs data generated by another task
  - Parallel dependency – A group of tasks *must* execute at the same time
  - Independence – Tasks are truly independent and can execute in any order

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Group Tasks

- Grouping tasks simplifies dependency analysis
  - Dependencies between groups can be resolved once per group instead of once per task in each group
  - This principle guides the grouping...pick groupings that simplify the dependency analysis

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Group Tasks

- Look at the original problem decomposition
  - High-level operations or loops are central to most task decompositions
    - Tasks that correspond to high-level operations usually group together
    - Tasks within a high-level operation that share a constrain should remain as a separate group
- Merge groups that share a common constraint
  - Larger groups make scheduling and load balancing easier

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Group Tasks

- Look at constraints between groups
  - If groups have a clear ordering or a clear data flow, this is easy
  - However, independent task groups may share constraints
    - It may be better to merge these groups

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Order Tasks

- How must task groups be ordered to satisfy all constraints?
- Create a partial ordering of tasks by identifying ordering constraints among groups
  - Ordering must be restrictive enough to satisfy all constraints
    - Design is not correct otherwise!
  - No more restrictive than necessary
    - Additional constraints limit flexibility in load balancing

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Order Tasks

- For each group, identify data required before that group can execute
  - To identify the ordering constraint, find the task / group that creates that data
- Determine if external services impose addition ordering constraints
  - Classic example is file I/O...different tasks may have to write data to a file in a particular order
- Also note when there is *no* constraint
  - Makes it more clear that potential interactions have been examined

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Data Sharing

- Determine *how* and *when* data is shared among tasks
  - Data that is statically partitioned to particular tasks is task-local
  - Data that cannot be strictly associated with a particular task is shared
    - This is the source of most dependencies
  - Task may also need access to a *portion* of another task's data
    - Usually boundary data that neighbors that tasks local data

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Data Sharing

- Impacts both correctness and efficiency of the program
  - Incorrect sharing can lead to some tasks getting incorrect data (reading before data is written)
  - Synchronization on global data can incur a lot of overhead
  - Excessive communication can also incur a lot of overhead
    - Condition variables, message queues, etc.

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Data Sharing

- Identify data that is shared among tasks
  - Look back at the original program decomposition for clues
- Classify each shared data
  - Read-only – Data the is not modified does not need to be protected
  - Effectively-local – Global data that is partitioned into per-UE subsets needs limited, if any, protection
  - Read/write – Data that is both read and written arbitrarily needs the most synchronization

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Data Sharing

- Special cases of read / write data:
  - Accumulate – Partial results are accumulated together to form a final result
    - Typically each task has a copy of the data where it accumulates partial results
    - When all tasks are complete, each local copy is accumulated into the final result
  - Multiple-read / single-write – Data is read by multiple tasks, but only updated by one
    - All readers need the initial value
    - The writer can modify the data arbitrarilly
    - Two copies of the data are required (constant initial and modifyable)

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Design Evaluation

- Evaluate the design *so far*
  - Decide whether or not to return to earlier steps or move on to the next step
  - The earlier design flaws are caught, the easier they are to fix!

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Design Evaluation

- Suitability for target platform
  - Does the design match the number of PEs available?
  - How is data shared among the PEs?
    - Different data partitionings fit SMP, NUMA, etc.
  - Are there sufficient UEs to mask I/O latency, etc?
  - Ratio of time spent doing useful work vs. overhead
    - Synchronization primitives (and available atomic operations) vary from platform to platform

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Design Evaluation

- Flexibility
  - Flexible in the number of tasks generated?
  - Is the definition of tasks independent of scheduling?
  - Is the size of data chunks parameterizable?
  - Does the algorithm handle boundary cases?

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Design Evaluation

- Efficiency
  - Can the load be balanced amont PEs?
  - Is overhead minimized?
    - Thread creation?
    - Synchronization?
    - Message passing?
    - etc.

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Design Evaluation

- Simplicity
  - Is the design as simple as possible without missing necessary components?

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Design Evaluation

- Other issues:
  - How regular are tasks and their dependencies?
  - Are interactions between tasks synchronous or asynchronous?
  - Are tasks grouped in the best way?

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References

Much of this lecture comes from the following two sources:

Berna L. Massingill, Timothy G. Mattson, and Beverly A. Sanders; "Patterns for Finding Concurrency for Parallel Application Programs"; *Proceedings of the Seventh Pattern Languages of Programs Workshop (PLoP 2000)*, 2000; http://jerry.cs.uiuc.edu/~plop/plop2k/proceedings/proceedings.html

Beverly Sanders, “A Pattern Language for Parallel Programming”; http://www.cise.ufl.edu/research/ParallelPatterns/sasplas.ppt

See also http://www.cise.ufl.edu/research/ParallelPatterns/

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Next week...

- Algorithm structure
  - Task Parallelism
  - Divide and Conquer
  - etc.
- Supporting Strcutures
  - SPMD
  - Master / worker
  - Loop Parallelism
  - etc.

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