The Future of Memory

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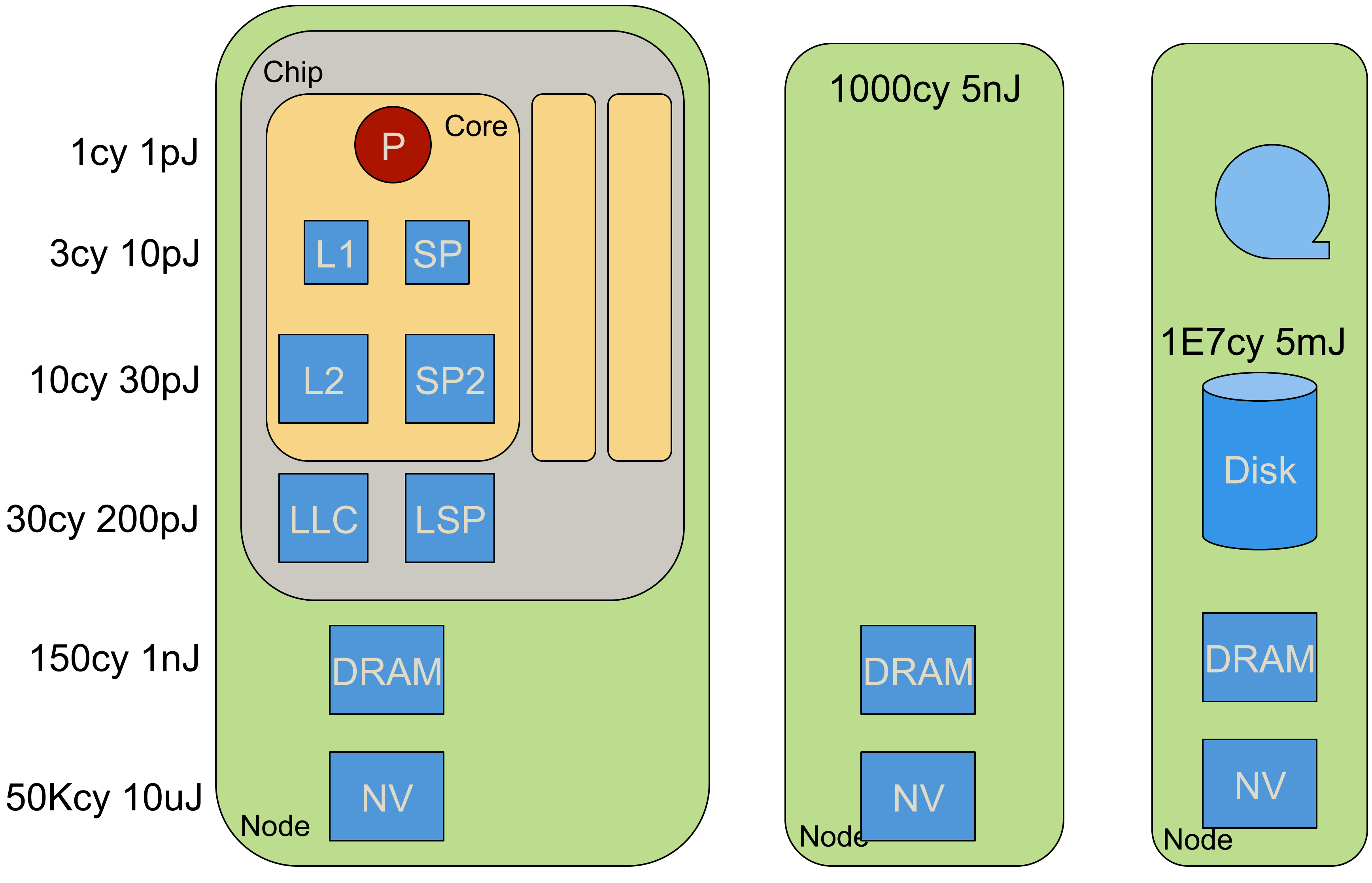
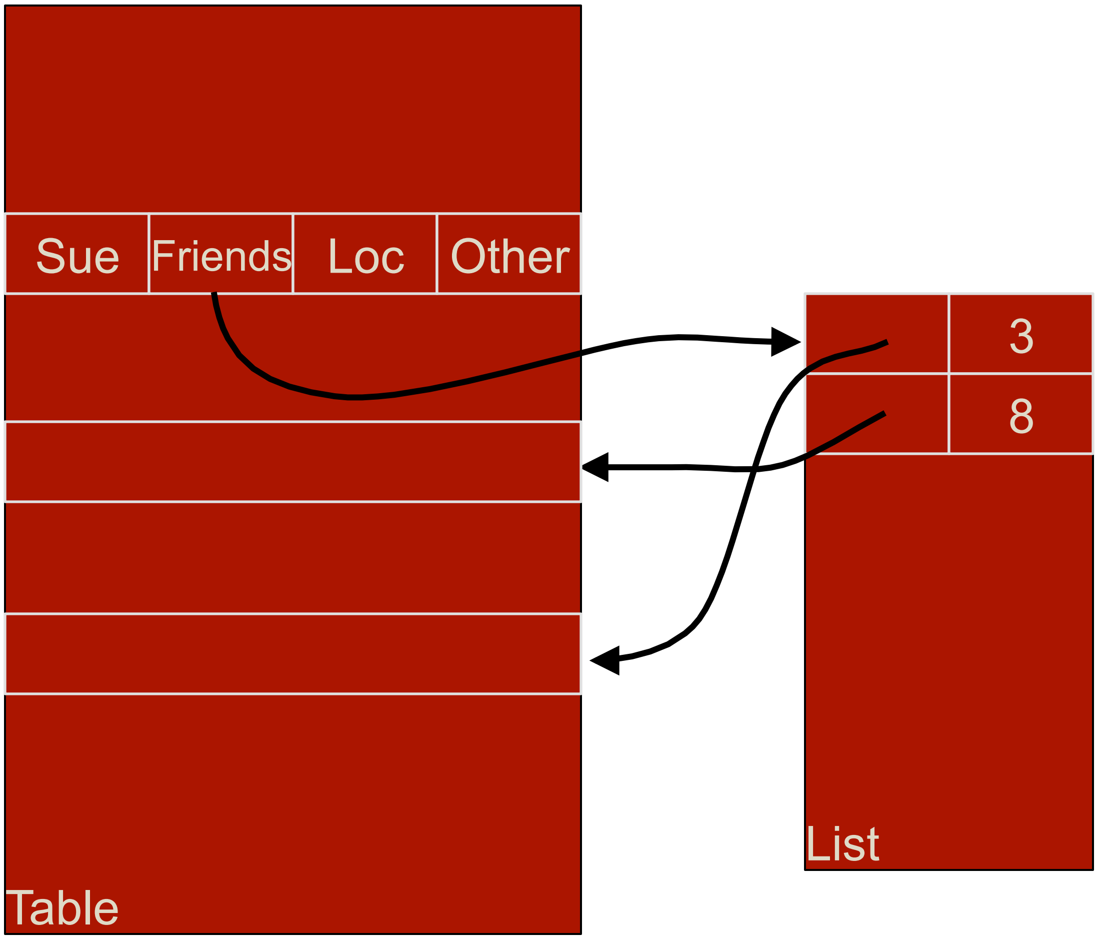
Physical Structure of Memory



Logical View of Memory



Mismatch Between

- Physical structure of memory
- Logical view of memory
- Architecture and mechanisms that expose memory

Obsolete Assumptions

- NV storage is a very slow block device
- Apps exhibit high temporal locality
- Move data to the compute

- No longer the case
  - Apps with massive, in-memory datasets
    - KV stores, graph systems, No-SQL databases,search …
    - Limited locality as they serve requests from millions of users
  - Storage class memories (SCM): fast & byte-level
    - PCM, resistive RAM
  - Moving computation to the data
    - For energy efficiency

The Requirements

- Need to rethink HW & SW for memory systems

- Features needed
  - Very high capacity memory systems
    - All data in some kind of fast memory
  - Support for heterogeneity: DRAM + SCM
    - And a deep hierarchy
  - Support for aggressive sharing
    - Between applications on a single node
    - Between nodes in a rack (disaggregation)
  - Near data processing
  - Security and privacy

Files & Pages Will not Cut It

- Pages
  - Wrong granularity
    - Too coarse for data movement
    - Too fine for protection and translation
  - Inflexible
  - Difficult to share (pointers in different address spaces)
- Files
  - Very heavyweight abstraction
  - Overheads of serialization/deserialization

Towards a One-Level Store

- Single address space spanning
  - Levels of storage (cache to NV)
  - Nodes

- No need to translate pointer structures
  - From file to DRAM
  - From node to node

Segments with Attributes

- A segment represents a set of records
  - Table, list, etc…
- Segments have “attributes”
  - (see next slide)
- Pointers identify a record within a segment

Attributes

- Logical attributes:
  - Size
  - Persistence
  - Durability
  - Mutability
  - Sparsity
  - Managed
  - Indexed
  - Locality patterns
  - …
- Physical attributes:
  - Location(s)
  - Representation (encoding)
  - Distribution
  - Replication
  - Encryption
  - Compression

Users specify logical attributes
Mappers determine physical attributes
Hints may be provided to help the mappers

Basic Operations

- seg = create_segment(rows, cols, persistent, sparse) ;
  - Sparse segments require ranges of rows to be materialized
- free_segment(seg) ;
  - May be implied by scoping, or automatic via GC
- rec = get_record(seg,offset)
- value = get_field(seg, offset, field)
  - Load
- set_field(seg, offset, field, value)
  - Store
- get_indexed(seg, field, value)

Implications

- A file is just a persistent segment
  - It may be bound to a name in a directory
- A database is just a set of persistent, durable segments
- A key-value store is just a persistent, durable, indexed segment
- Segments may be shared across nodes and between processes within a node
- Segments may be mapped across nodes and over levels of storage within a node
- Parts of segments may be replicated, compressed, not there, etc…

Scenarios

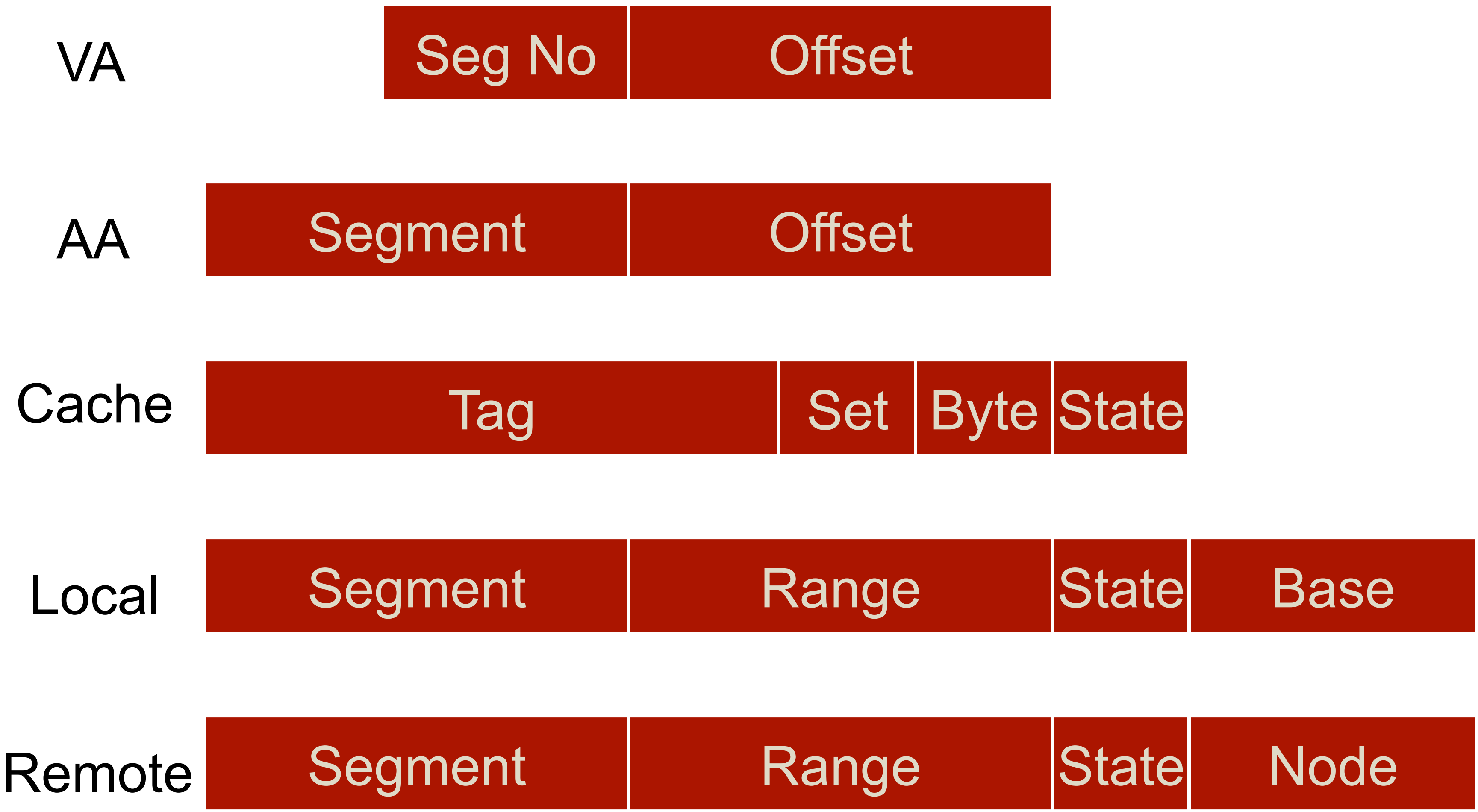
- A process can create a segment larger than the DRAM on its node
  - Disaggregated memory
- Pointer structures in files can just be used
  - No need to remap between two address spaces
- Persistent segments are automatically mapped to NV memory and/or disk
  - But cached in DRAM, SRAM, or SCM when in use
- Durable segments are automatically replicated as needed

Mapping

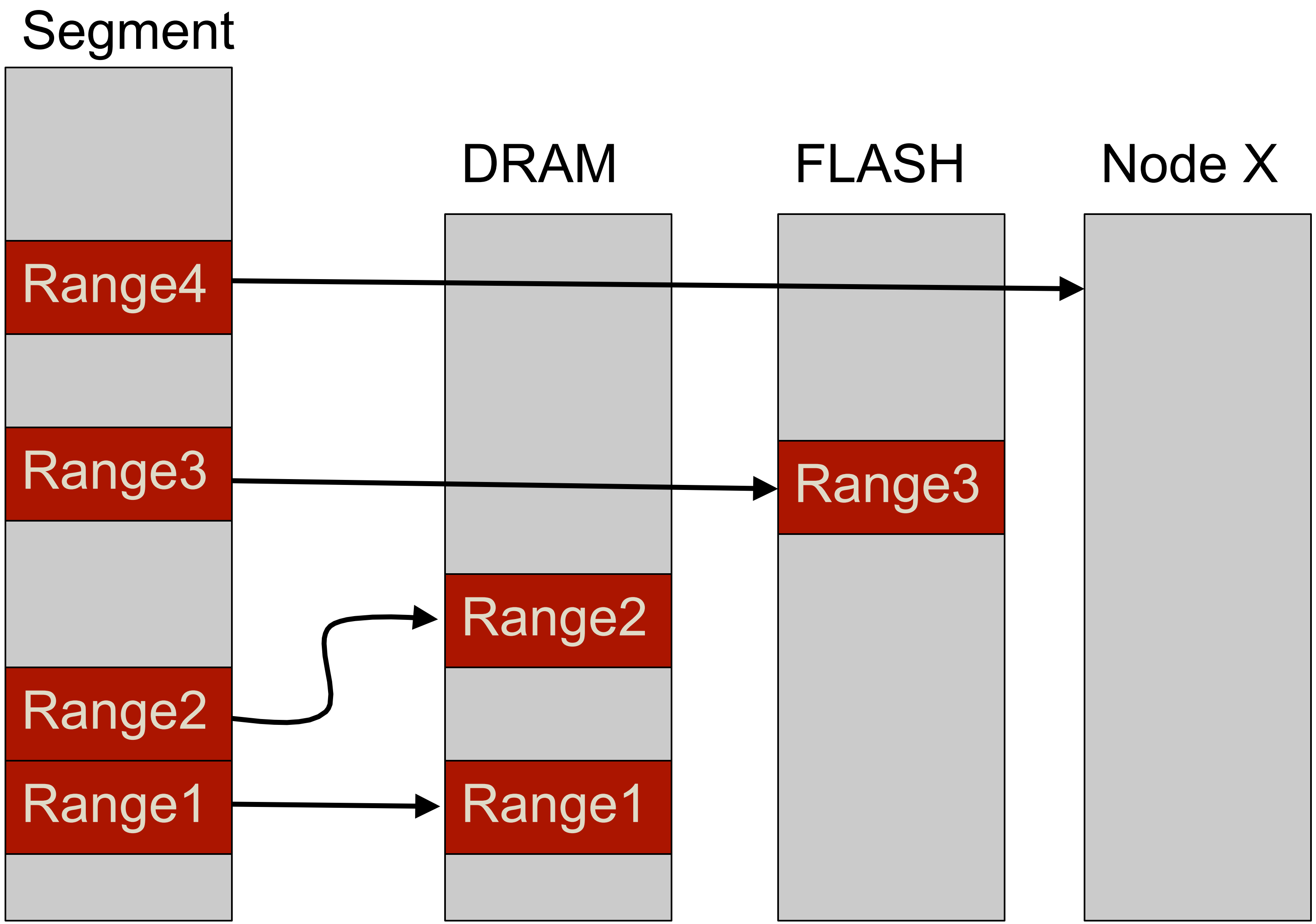
- Mapping policy decides where portions of a segment are located and replicated.
- Access mechanism
  - Validates access
  - Locates nearest copy for reads
  - Maintains coherence and consistency for writes
  - Fast (hardware) access to near levels of storage
  - Flexible (software) access to others

Mapping Mechanisms

(Range Matching)



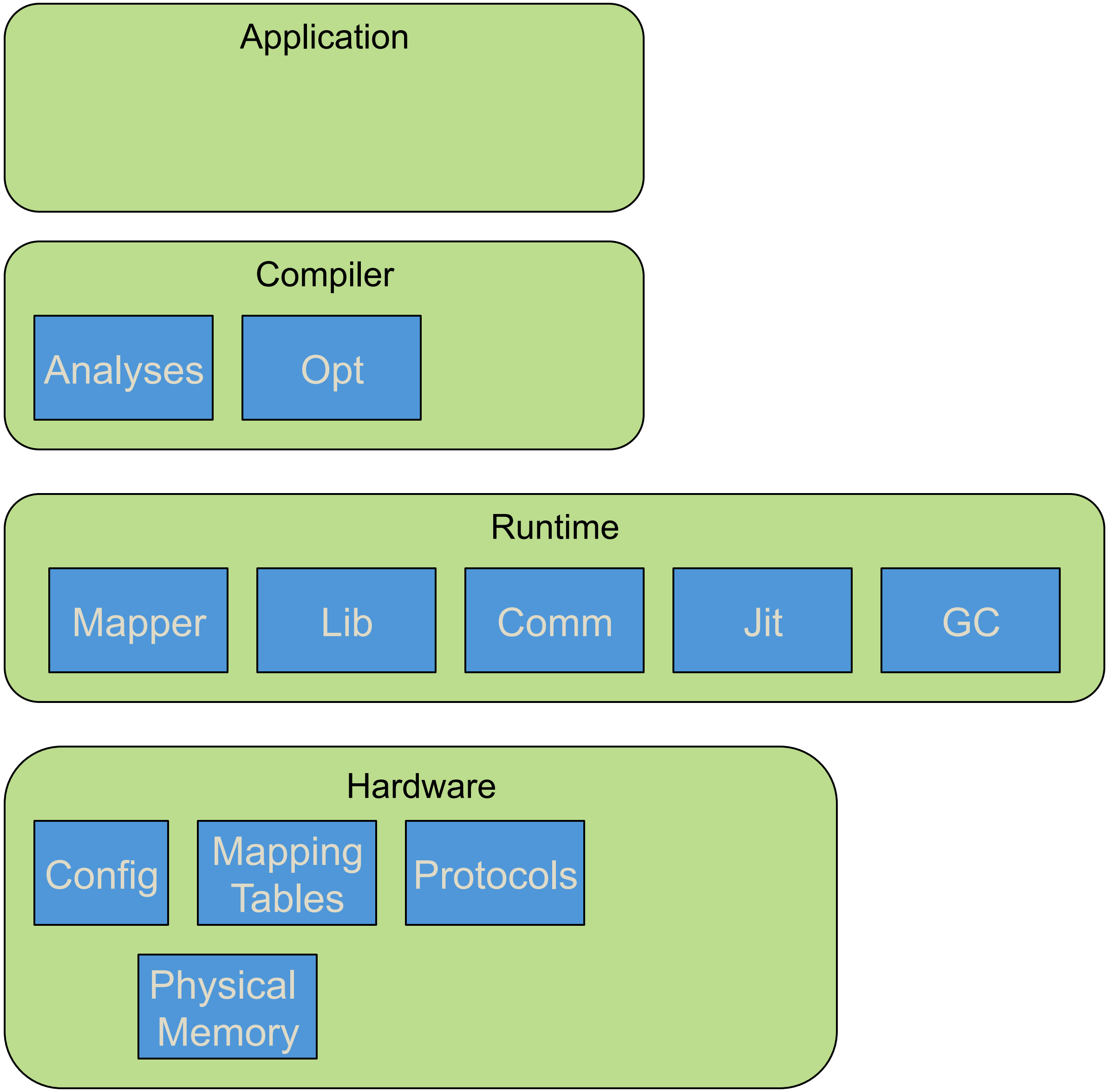
Mapping Example



Just say No to Pages

- Too fine a granularity for mapping
  - 256M 4K pages in a 1TB memory system
  - Huge page tables with redundant information
  - TLB thrashing
- Too large a granularity for communication
  - Want to send 8-64B, not 4K
- Doesn’t handle replication well

System Structure



Some Research Questions

- Mapping policies and mechanisms
  - In a single node, in a rack, in a datacenter
- API to provide hints
- Division of mechanism between HW, runtime, compiler
- Pointer compression
- Compilation (JIT) to remove translation
- Resilience mechanisms
- Efficient hardware structures and mechanisms
- Capabilities
- Privacy and security (flow tracking & control)
- Integration with distributed execution
  - Load balancing, near data processing, …
- Support for dynamic types