# OpenPOWER: Reengineering a server ecosystem for large-scale data centers

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# OpenPOWER is about choice in large-scale data centers


- build workload optimized solutions
- use best-of-breed components from an open ecosystem

- collaborative innovation in open ecosystem
- with open interfaces

- delivered system performance
- new capabilities instead of technology scaling

# Competing Forces Are Shaping the Data Center Landscape

*Need for Standardization*

*Need for Innovation*


**Hardware Development**

- ⇨ Consumer Scale Volumes
- ⇨ DIY servers

**Software Development**

- ⇨ Known Software Stack
- ⇨ Higher Programmer Productivity

**“X86 Everywhere”**

**Hardware Development**

- ⇨ Optimize for Servers
- ⇨ Increase Value & Differentiation

**Software Development**

- ⇨ Portability & Platform Choice
- ⇨ Workload Optimization

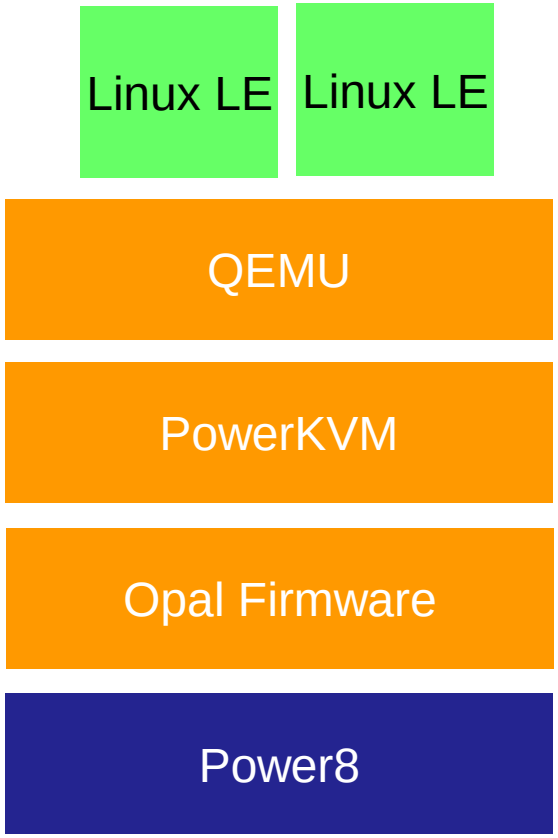
**One Size Does Not Fit All**

# OpenPOWER unchains scale out data centers

- A consortium of data center suppliers and operators
- Jointly create vibrant open ecosystem for data centers
- Expand options for large-scale data center computing
- Software stacks as true measure of ecosystem

# OpenPOWER ecosystem framework

- Enable rich ecosystem of hardware vendors
  - Standardized hardware interfaces
  - ⇨ Common, open firmware interfaces
- Open source system software stack
  - Data center operators rely on tuning SW stack
  - Enable server ODM vendors to create offerings
  - ⇨ Operating environment built on Linux and KVM
- Simplify porting of scale-out data center applications
  - Application source code dependences
  - In-storage data base formats
  - Exploit I/O and accelerators originally designed for PCs
  - ⇨ Little-endian data format and programming interfaces



# A new Open Power Linux environment

- OpenPOWER is not the traditional Power Linux with a new name
  - Significant discontinuity and fresh start
  - No Binary Compatibility to Legacy Power Linux
    ⇨ new environment “ppc64le”
  - New: Firmware, Hypervisor, data layout, source code, ELFv2 ABI

- What changes for application developers?
  - Byte order
  - New ABI
  - Vector programming API

- Extremely rapid turn-around from decision to develop to deployment
  - First discussions in March 2013, Linux distro builds starting October 2013
  - >40000 packages built within short time

# The New OpenPOWER Application Binary Interface (ABI)

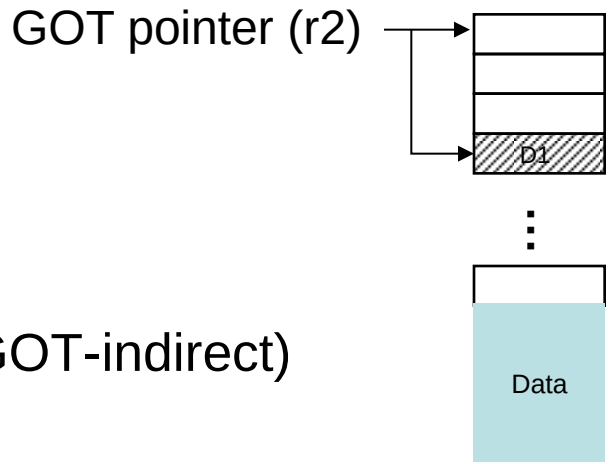
- Starting point: PPC64 / AIX ABI
  - Established, tested production code
  - Commonality and maintenance across LE, BE and AIX where feasible
  - Minimum disruption for tooling: GCC, XL, Java, LLVM, libffi, PyPy, …
- Define new capabilities as delta over baseline
  - Align with the broader ecosystem
  - Create hardware optimization opportunities / synergies
  - Optimize for modern code patterns
    - More classes, abstraction
    - Shorter function lengths
    - More indirect calls
- **If it ain't broken, don't fix it!**

# Optimizing Data Access with the Global Offset Table (GOT)

- Initialize pointer to GOT without functions descriptors
  - Dual entry points to re-use GOT on local call
- Optimize GOT pointer update on cross-module calls
  - Schedule GOT pointer save in caller
- Expand addressing range with “Medium Code Model”
  - Exploit Fusion and avoid GOT overflow code
- Optimize GOT in main module
  - Generate non-PIC code and resolve symbols at link time

# Global Offset Table (GOT)

- Global Offset Table: data dictionary
  - Holds addresses for global data
- The GOT pointer points to data dictionary
  - load data address for indirect access (GOT-indirect)
  - load data directly (GOT-relative)
- Each module (shared library) has a different GOT
  - Cross-module calls save/restore old and load new GOT pointer



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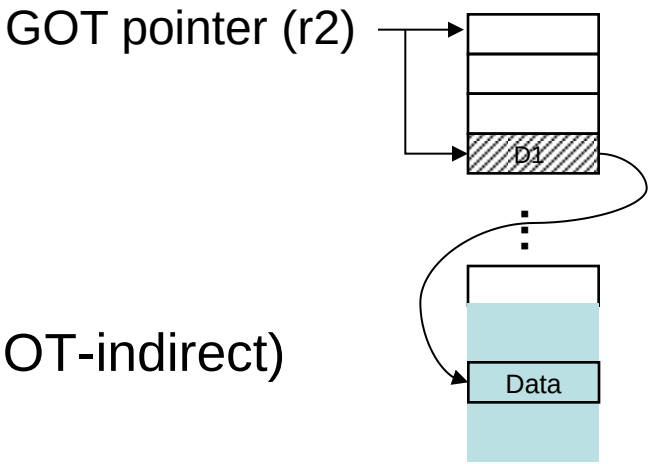


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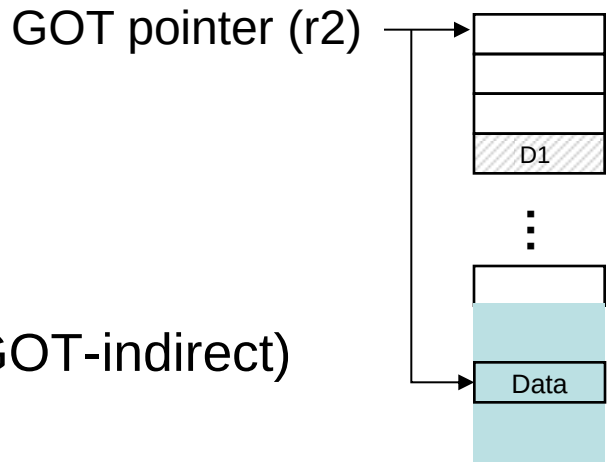
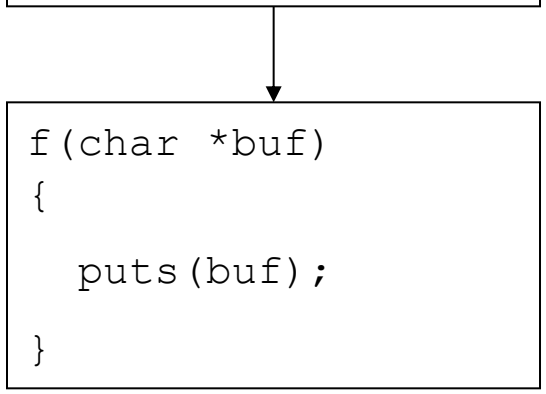


# Establishing the GOT pointer

- Two entry points for each function
  - "Local EP": shared GOT in same module
  - "Global EP": initialize new GOT for module
  - Symbol table points to Global EP
- Direct call provides current GOT pointer (in r2)
  - Linker resolves local call to Local EP
  - Linker resolves extern call to PLT stub
    - Extern call resolved by dynamic linker
    - PLT stub performs indirect call to function
- Indirect calls to Global EP
  - Function entry address in r12

```
f: ; r12 points to func entry
  addis r2, r12, (.TOC.-l0)@ha
  addi r2, r2, (.TOC.-l0)@l
.localentry f, 2
```

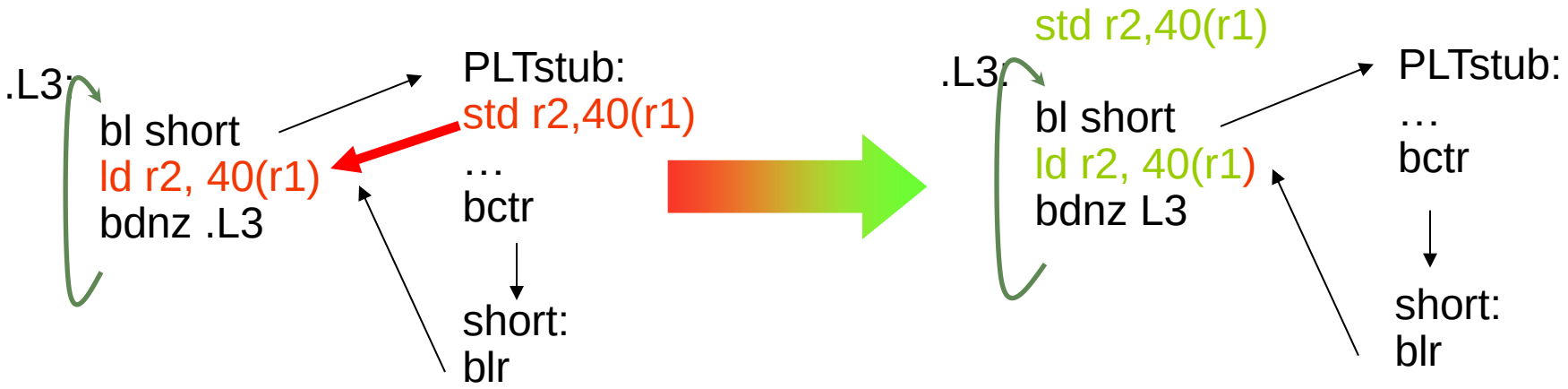


# Optimizing GOT pointer save and restore

- Compiler collaborates with linker
  - Reduce GOT management overhead
- Optimizing placement of GOT pointer save points for external calls
  - Compiler schedules a placeholder for a GOT pointer save
  - Static linker populates placeholder with GOT save instruction **if and only if** an external function call is made

# Call cost reduction with scheduled GOT store

- Remove repeated store of GOT pointer
- Avoid forwarding of in-flight store to dependent load



# Medium Code Model

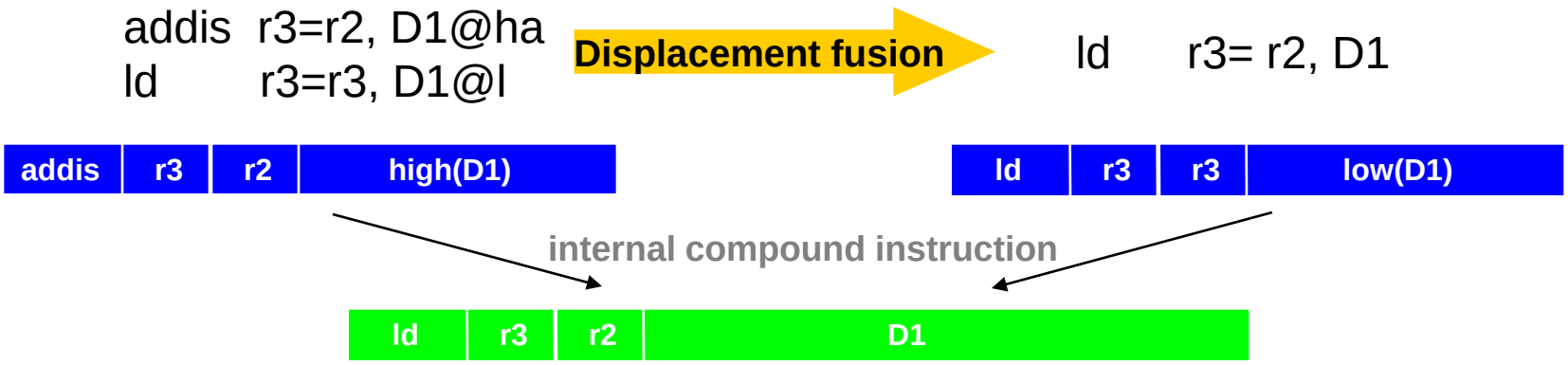
- "Medium code model" addresses growing data size
  - Expand GOT data dictionary to up to 4GB
  - Memory access with 32b displacement

- The size of the data dictionary is constrained by displacement range
  - Fixed width RISC ISA constrains the displacement to 16b
    - 64KB "natural" dictionary size (8k variables)
  - Dictionary overflow handling can penalize performance

- "Medium Code Model" as default: facilitate organic application growth
  - Enable applications to grow beyond 8K to 500M variables per module
  - "Beyond RISC" using Displacement Fusion capability in Power8

# Beyond RISC: Displacement Fusion

- "Fusion" allows processor to build **internal compound instruction**
  - Combine multiple instructions into internal compound instruction
  - CISC addressing range while retaining RISC fixed-width advantage
- Compound instruction executes as a single hardware operation
  - Fewer resources, shorter latency
  - Improved performance for programs with large data sets



# Function Call Improvements

- Parameter passing
  - Pass/return more parameters in registers
- Streamline stack frame
  - Allocate parameter save area only when required
- More descriptive object file info
  - More precise DWARF, Reloc's, and ELF format flags
  - Improve future ABI extensibility

# Register usage for function arguments

- Goal: Reduce abstraction penalty (“same performance as builtin types”)
  - OO languages wrap basic data types in a class
  - Previous Power ABI passes most classes via GPRs
  - … and returns most class results in memory
    - Other common ABIs pass and return class in memory
- Goal: Pass each data type in “natural” register
  - Integer parameters ⇨ general purpose registers
  - Floating point parameters ⇨ floating point registers
  - Vector parameters ⇨ vector registers

# Register usage for function arguments

- Pass more class types as register parameters
  - ⇨ Solution: homogeneous float/vector aggregates
  - – Up to 8 members passed in natural registers
- Return function results in same register(s) as first input parameter
  - – Aggregates returned in multiple registers
  - – Homogenous float and vector aggregates in float and vector registers
- Significant improvement for abstract data type handling
  - – 3x-4x performance improvement for invocations of class vertex<float>
  - – Class std:complex<> matches native _Complex type performance
  - – ~1%-5% performance improvement for many OO codes

# ABI performance

- Unchanged performance in programs with
  - Large functions / subroutines
  - Extensive inlining
- Faster performance in programs with:
  - Large GOT with many global variables
  - Calls to small functions
  - Pointer calls including virtual function calls.
  - Functions with abstract data types
  - …

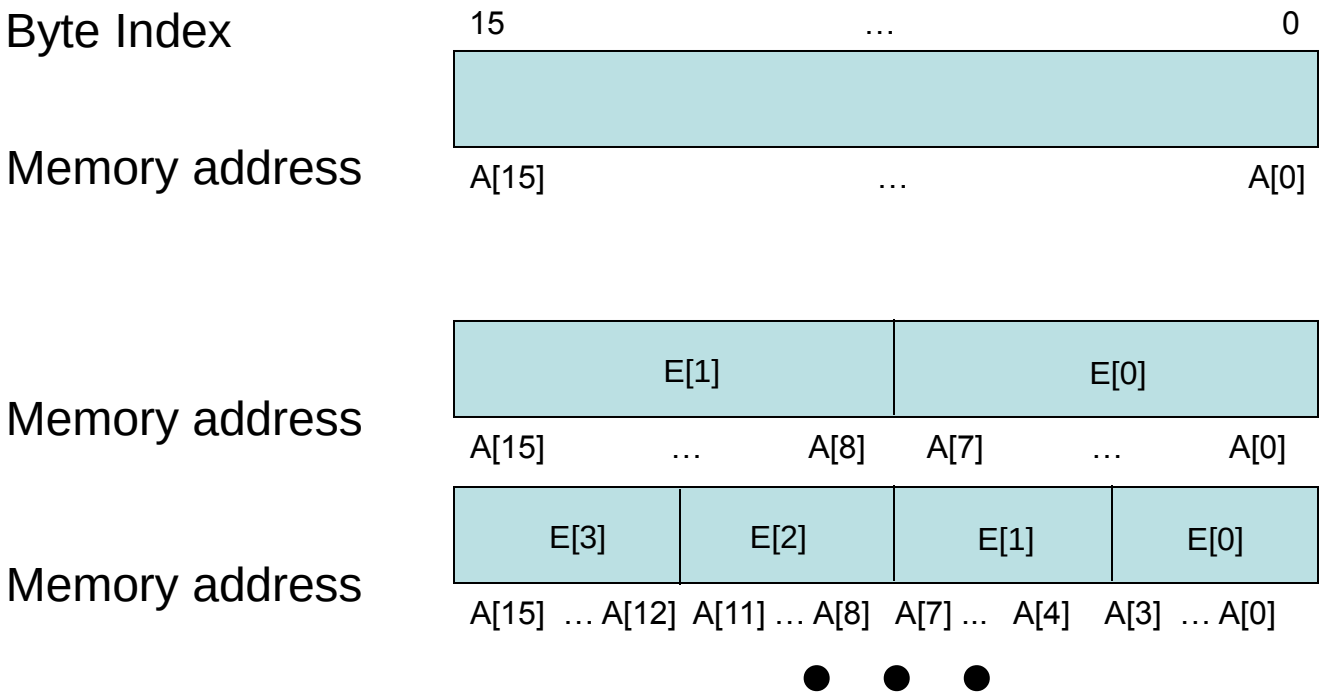
# OpenPOWER Vector SIMD Programming Model

- Transcends traditional hardware-centric SIMD programming models
  - Vector SIMD API describes *what* SIMD processing to perform, *not how*
  - API targets compiler, not hardware primitives
  - API independent of underlying hardware

- Goals: intuitive programming models and application portability
  - from other little-endian environments
    - consistently little-endian API and data layout
  - from big-endian environments (Power BE)
    - simplify porting and sharing of libraries between LE and BE environments
    - exploit large body of numeric middleware developed for Power

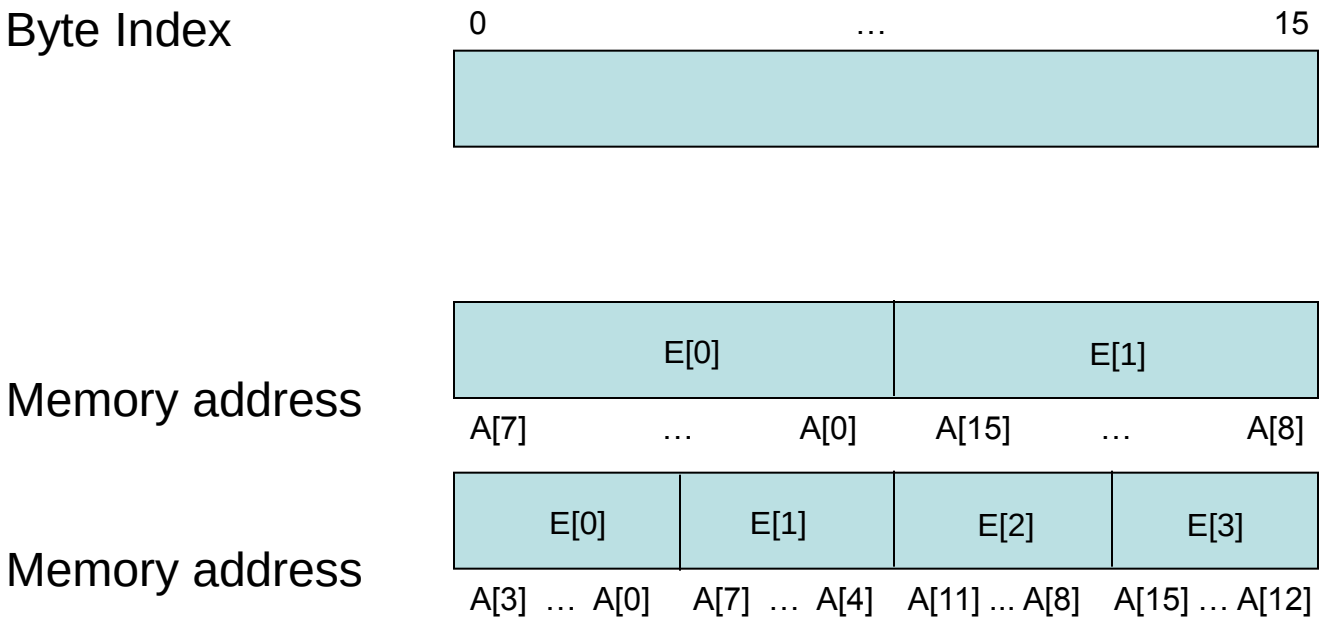
# The “True Little-Endian” Vector Model (Default LE Vector API)

- OpenPOWER Little-Endian Model
  - Focus on programmability – consistent little-endian view
  - Focus on ease of sharing code with other little-endian ecosystems



# The “Big-on-Little-Endian” Vector Model (Optional BE Portability Model)

- “Big-on-Little-Endian” Model ➔ Optional Model for Porting of BE Libraries
  - Focus on porting of Big-Endian code with Big-Endian register layout
  - Focus on ease of sharing code between LE and AIX / BE Linux

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# OpenPOWER Little-Endian API Implementation

- Vector API model selected by command line switch
  - Native (default) API is to “True Little Endian”
  - Compiler command line to select “Big-on-Little” (GCC,XL)

- Compiler-based mapping of vector API to hardware primitives
  - True LE ➔ hardware instructions use big-endian register numbering
  - Big-on-Little ➔ bridge BE/LE data layout on memory accesses
    - Power ISA provides support for transparent data adjustment

- Both models translated to common intermediate format
  - Compiler optimizes vector computations

# OpenPOWER available now

- Collaborative innovation already changing industry
  - Major data center stakeholders joining OpenPOWER
- Redefined software stack: Firmware, Hypervisors, OS, Applications
  - little-endian data model for simplified application porting
  - Linux distros available now ➔ 40000 packages ported
- New OpenPOWER environment enables
  - ease-of-use and out-of-box performance
  - exploitation of new Power8 hardware features

# Thank you!

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