Dresden Microelectronics Academy

Orchestration: Turning material breakthroughs into application performance

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(on behalf of the Orchestration team)

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Chair for Compiler Construction

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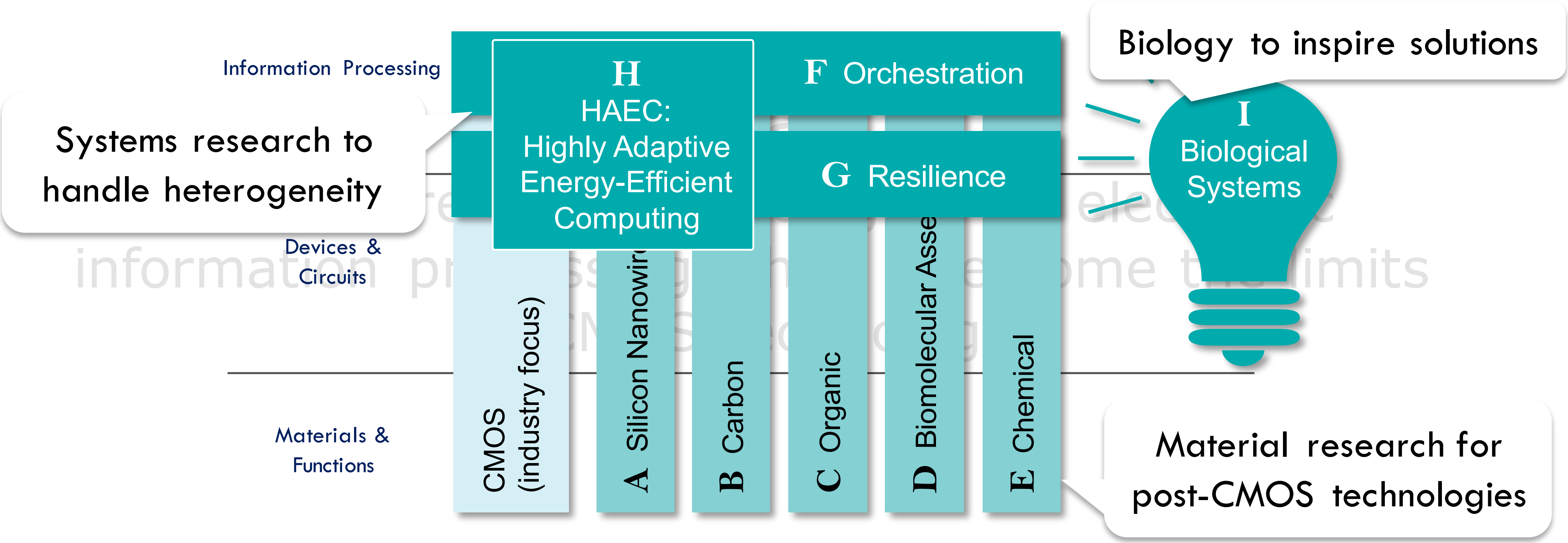
Cfaed: Research program (revisited)

Goal

to explore new technologies for electronic information processing which overcome the limits of CMOS technology

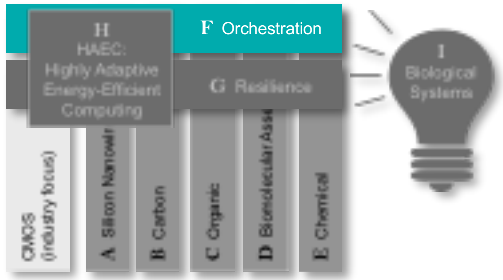
Cfaed: Research program (revisited)



Orchestration Path

Mission

Turn materials breakthroughs into application performance



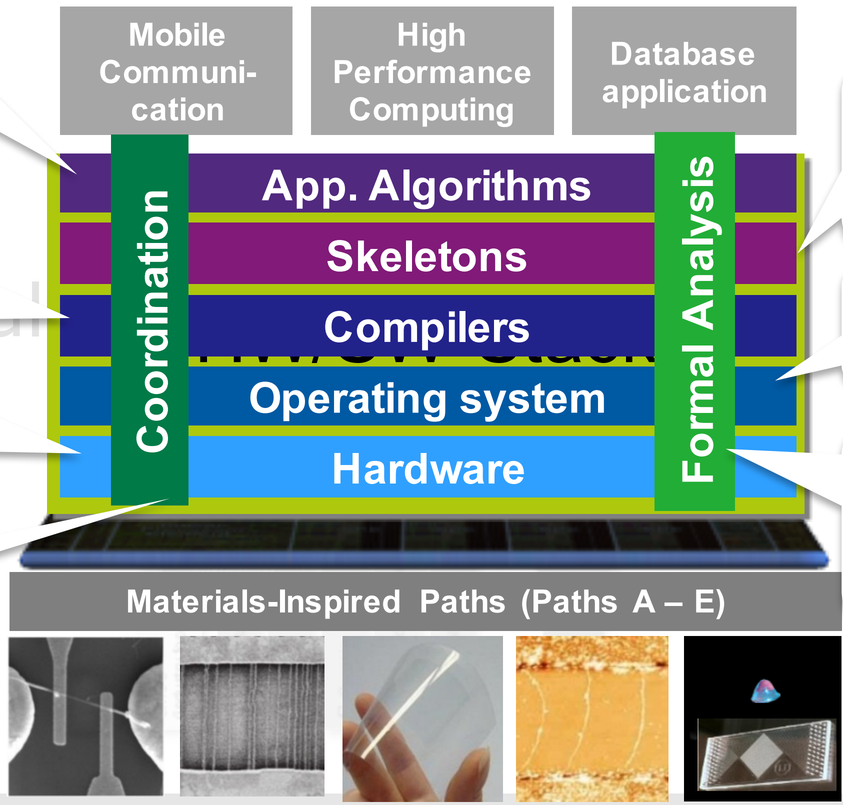
Orchestration Path

Underlying algorithms: self-adjusting

Code synthesis: variant generation

Heterogeneous “template”

Cross-layer strategies



Programming abstractions

“Micro-kernels”

System analysis: modeling, verification & reasoning

Orchestration Path: the team

- Investigators
  - Prof. Uwe Aßmann
  - Prof. Franz Baader
  - Prof. Christel Baier
  - Prof. Jeronimo Castrillon
  - Prof. Gerhard Fettweis
  - Prof. Christof Fetzer
  - Prof. Jochen Fröhlich
  - Prof. Hermann Härtig
  - Prof. Wolfgang Lehner
  - Prof. Wolfgang E. Nagel
  - Dr. Marcus Völp
  - Prof. Axel Voigt

Orchestration Path: the team (2)

- PhD/Postdocs
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  - Dirk Habich
  - Immo Huismann
  - Tomas Karnagel
  - Sven Karol
  - Sascha Klüppelholz
  - Linda Leuschner
  - Matthias Lieber
  - Siqi Ling
  - Steffen Märker
  - Johannes Mey
  - Benedikt Nöthen
  - Michael Raitza
  - Norman Rink
  - Annett Ungethüm

Outline

- Introduction
- **HW/SW stacks**
- Orchestration stack
- Outlook
- Concluding remarks

What is a stack

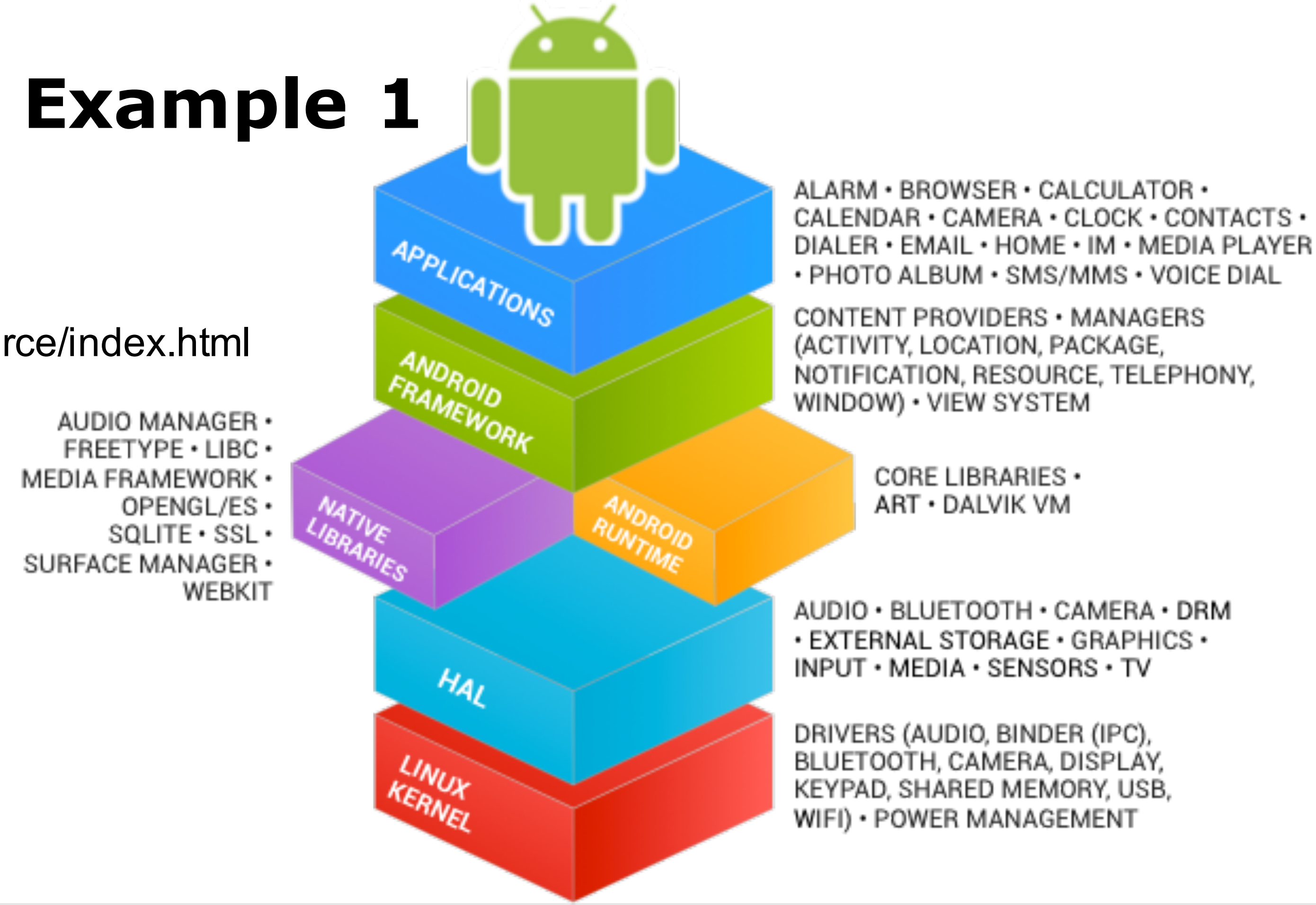
- Software components that form a complete platform (where you can run applications on)
  - Web app: Operating system, web server, database, programming language

- Provide means to handle complexity

HW/SW Stack: Example 1

Android sack

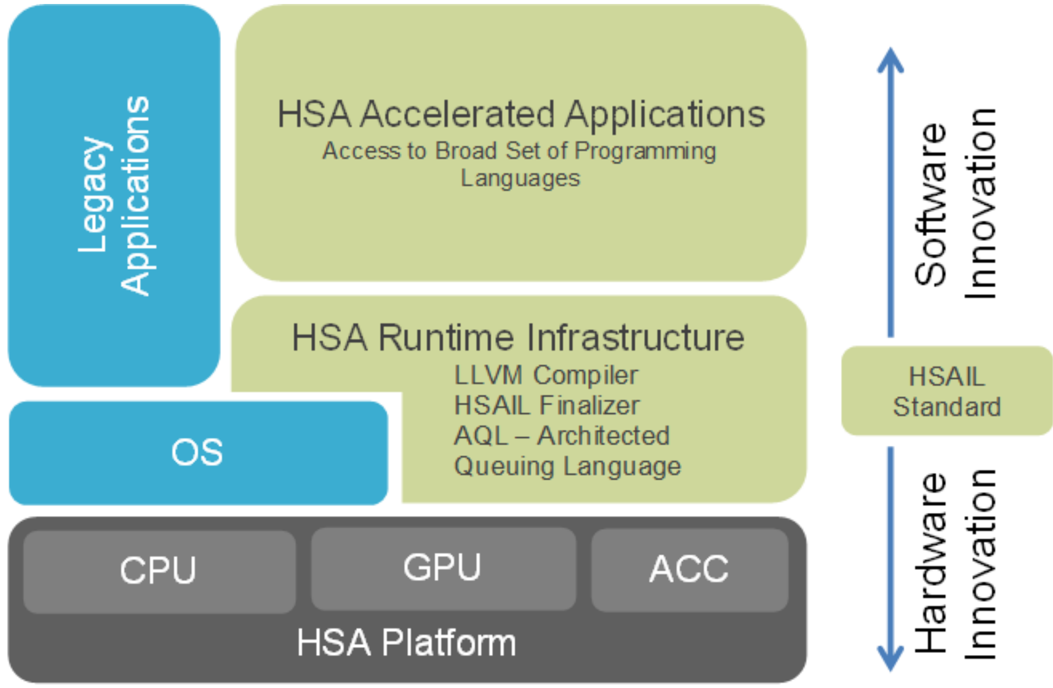
Source:
https://source.android.com/source/index.html



HW/SW Stack: Example 2

HSA Stack

Source: Heterogeneous System Architecture
http://developer.amd.com/resources/heterogeneous-computing/what-is-heterogeneous-system-architecture-hsa/



HSA Solution Stack

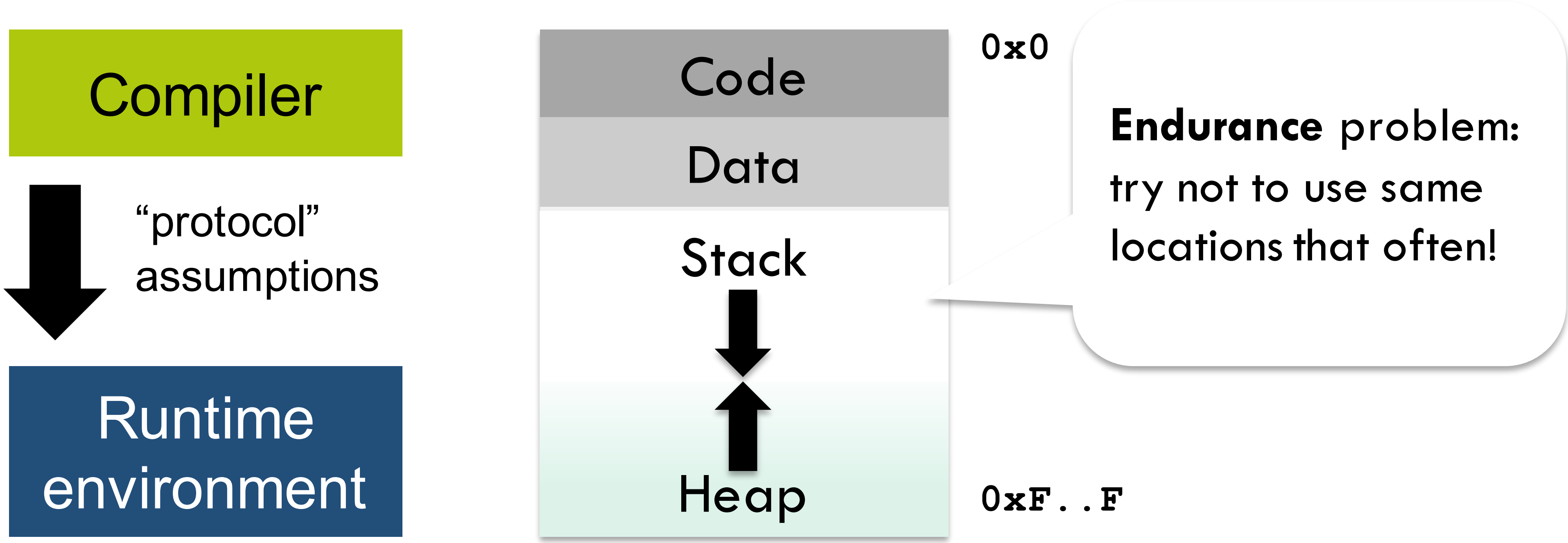
Stacks and wild heterogeneity

- Abstract/hide complexity
- Leave as much visible as needed for efficiency

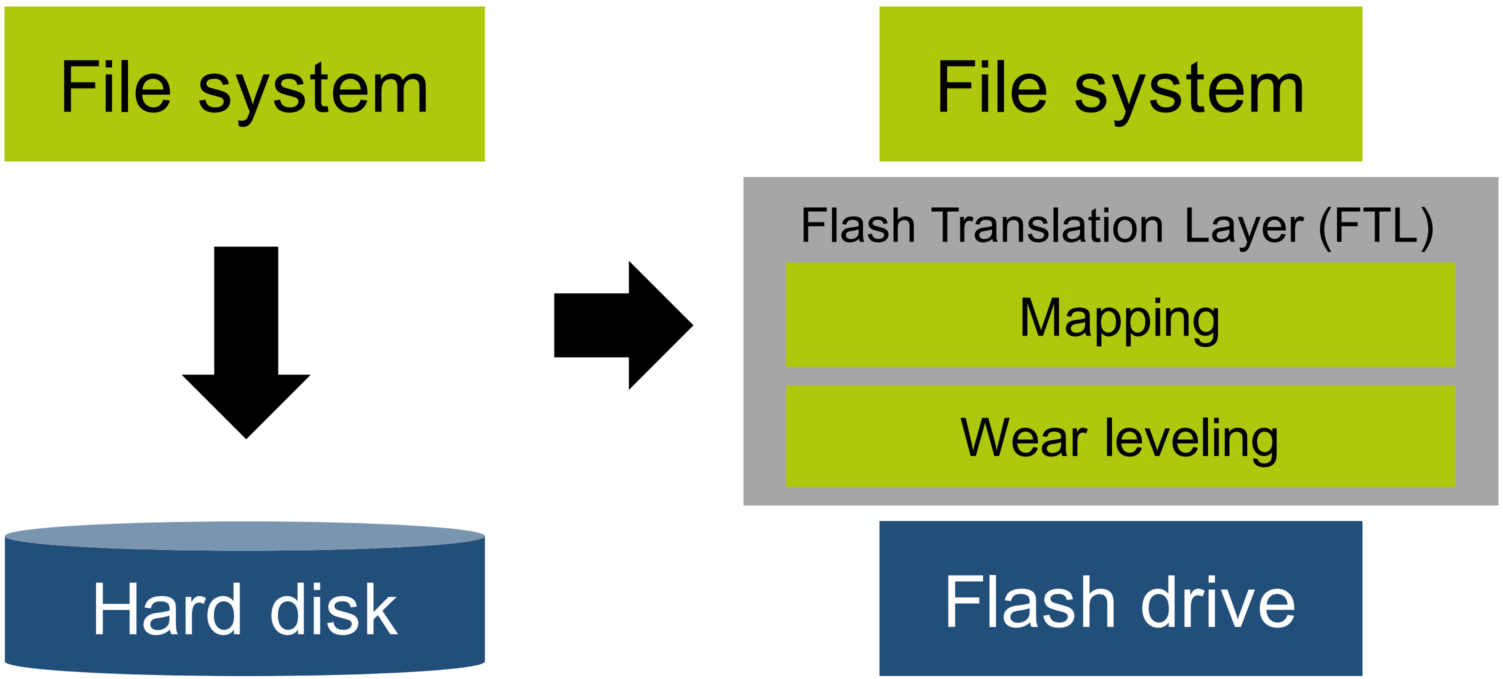
- Emerging techs.: rethink established layers
  - Languages, compilers, operating systems, …

HSA Solution Stack

Example: Compiler – Runtime



Example: Flash FTL



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- **Orchestration stack**
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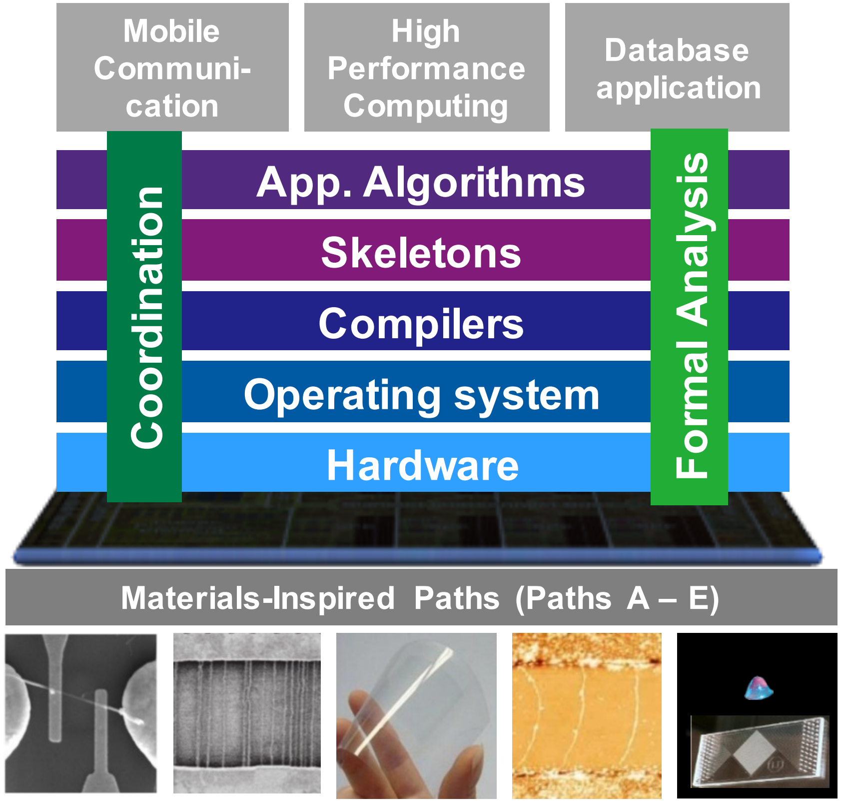
Recall: orchestration stack

- Heterogeneous materials
  - In Cfaed: Along with orchestration (see other DMA presentations)
- Research plan
  - Start with heterogeneous CMOS
  - Tiled for scalability, integrability
  - Pilot projects with materials as they become available



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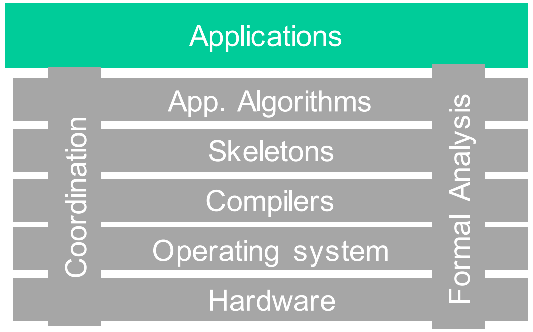
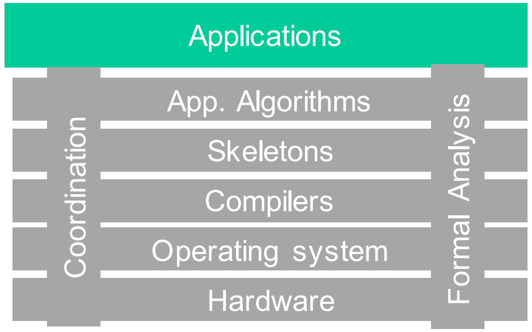


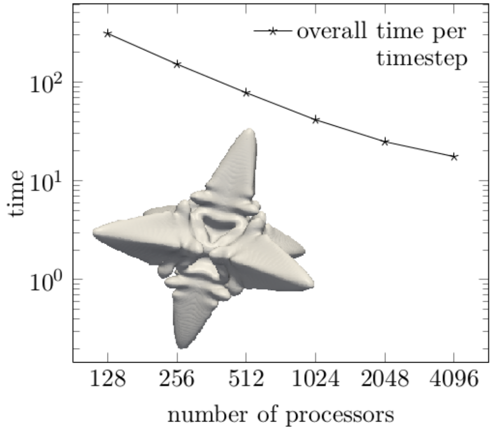
Applications/Drivers

- Mobile communication: typically run on heterogeneous
- Data-bases: benefits of heterogeneity (see below)
- HPC: high level languages, abstractions for scalability, productivity and portability
  - Adaptive Finite Element Methods (FEM)
  - Computational Fluid Dynamics (CFD)

Applications/Drivers (2)

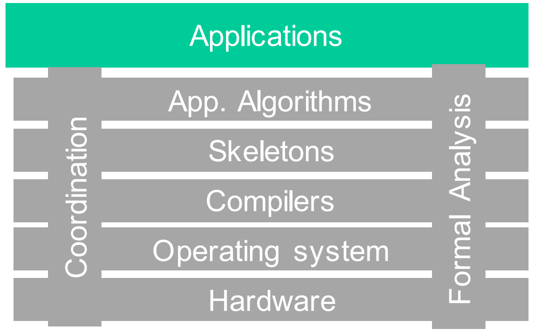


- Adaptive Finite Element Methods (FEM)
  - Working with multiple-meshes
  - Communication across subdomains
  - Requires repartitioning ➔ load balancing
  - Working on
    - Portable *templatized* library
    - First results on heterogeneous platforms



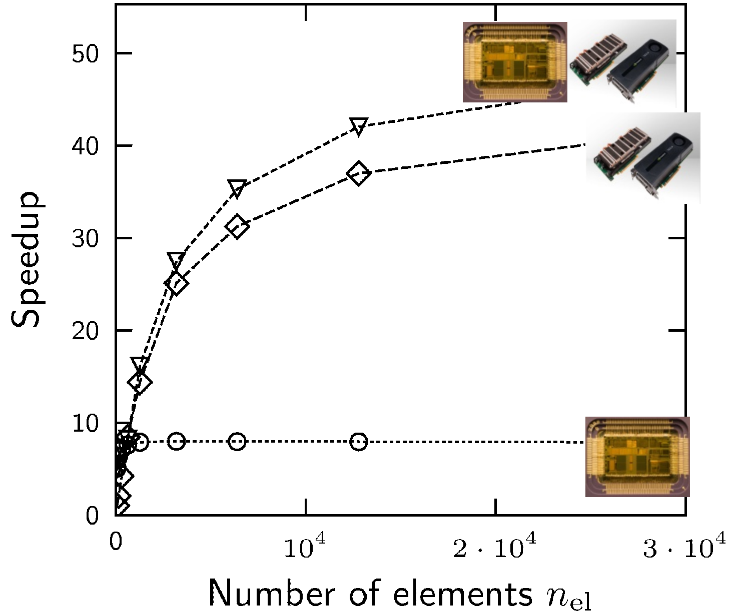
Dendritic growth

[Witkowski15]

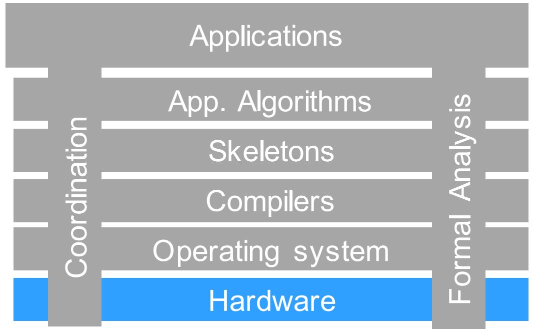


Applications/Drivers (3)

- Computational Fluid Dynamics (CFD)
  - Large applications (10^{10} unknowns)
  - Communication/computation is key
  - Working on
    - Heterogeneous implementation
    - More versatile fundamental concepts

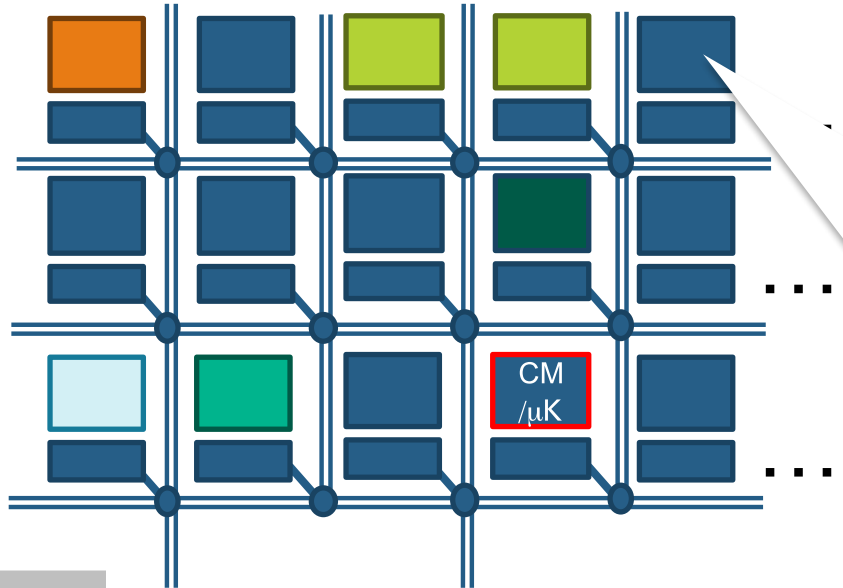


[Huismann15]



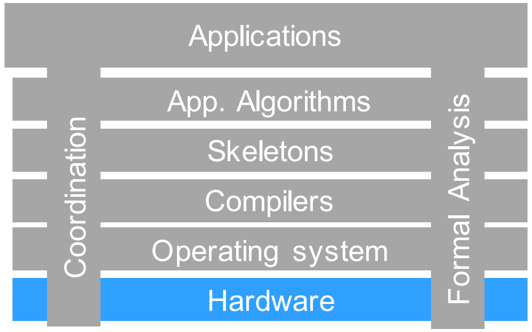
Hardware

- Tomahawk: heterogeneous CMOS



- Tiled (with NoC) for scalability
- Allows to integrate wildly heterogeneous components
- CoreManager (CM): HW support for fine-grained task dispatching

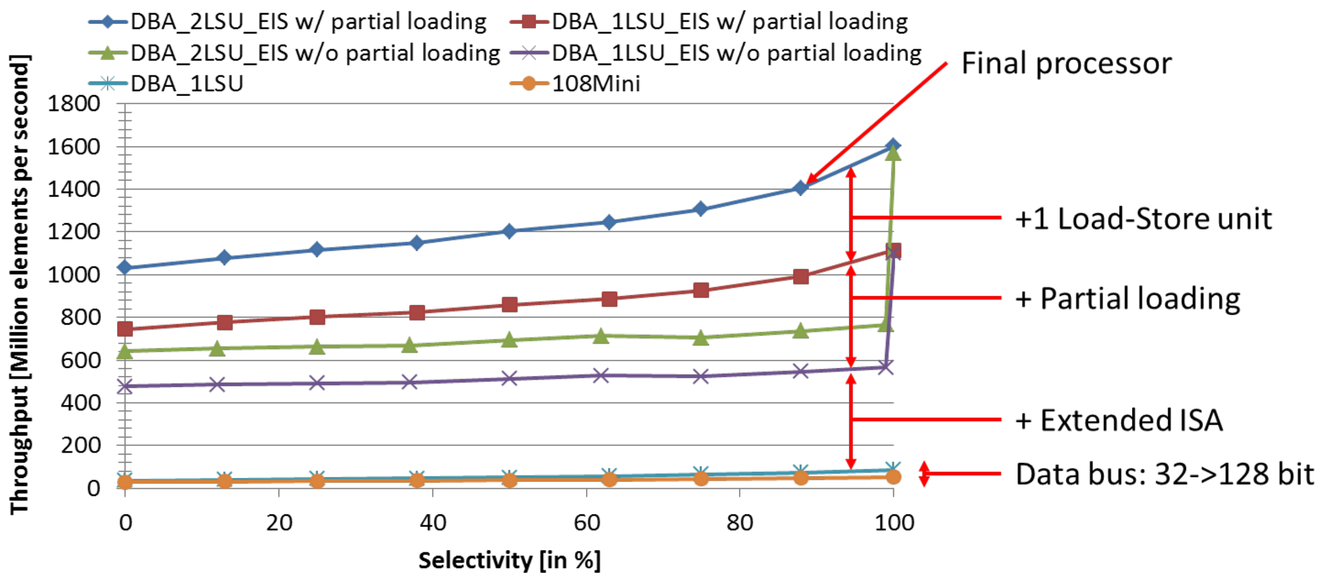
[Arnold13]



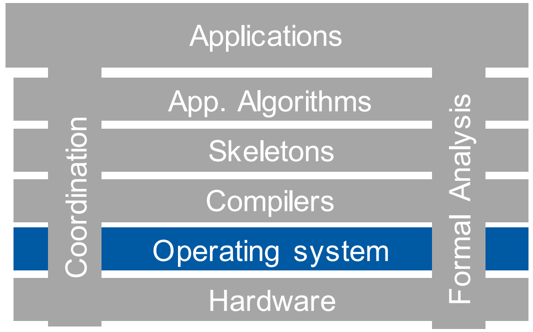
Hardware

- DB-processor for sorting algorithms

Selectivity:

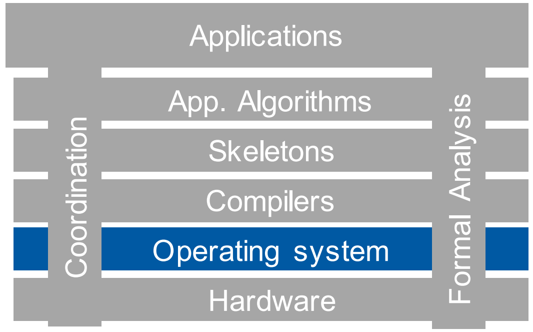


[Arnold14]



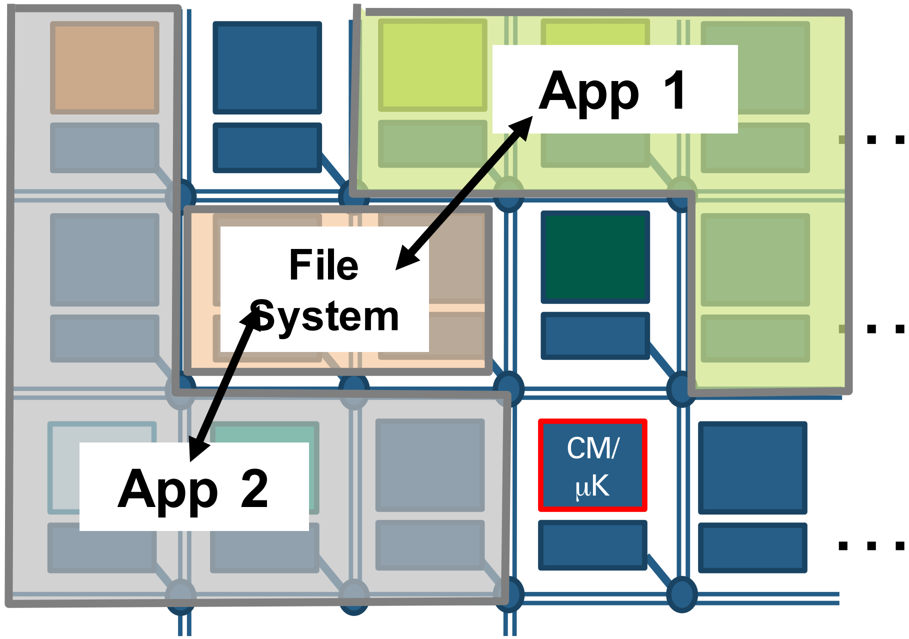
Operating Systems

- Microkernel for heterogeneity
  - Isolation (at NoC level)
    - Dynamic compartments
    - Isolation at network boundary
  - Remote control: no need for OS everywhere
    - Simplify integration of novel materials
    - OS services on remote cores



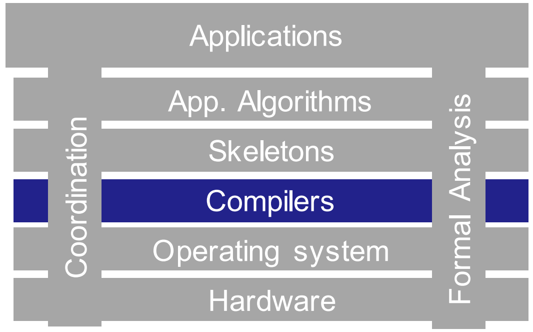
Operating Systems

- Microkernel for heterogeneity



Isolation & remote control

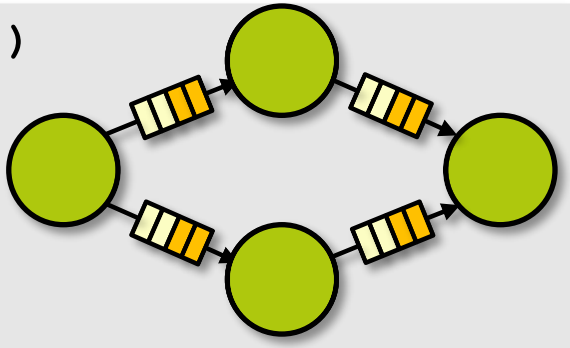
[Asmussen15]



Compilers

- Parallel dataflow programming languages and compilers

```
__PNkpn AudioAmp __PNin(short A[2]) __PNout(short B[2])
                 __PNparam(short boost){
  while (1)
    __PNin(A) __PNout(B) {
      for (int i = 0; i < 2; i++)
        B[i] = A[i]*boost;
    }}
__PNprocess Amp1 = AudioAmp __PNin(C) __PNout(F) __PNparam(3);
__PNprocess Amp2 = AudioAmp __PNin(D) __PNout(G) __PNparam(10);
```



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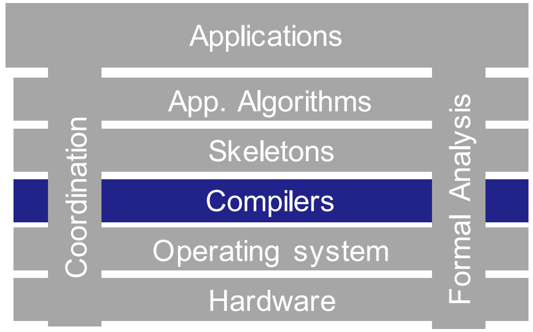
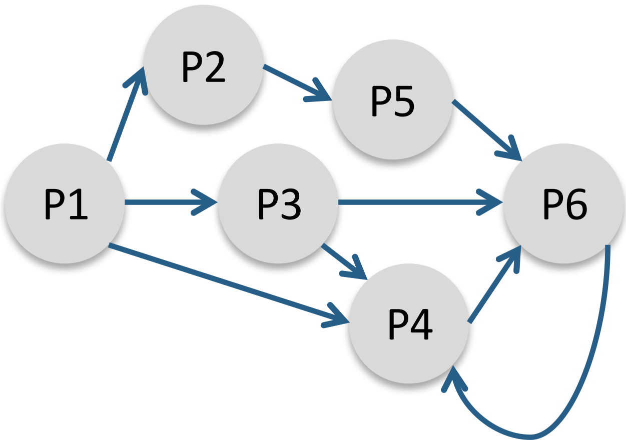
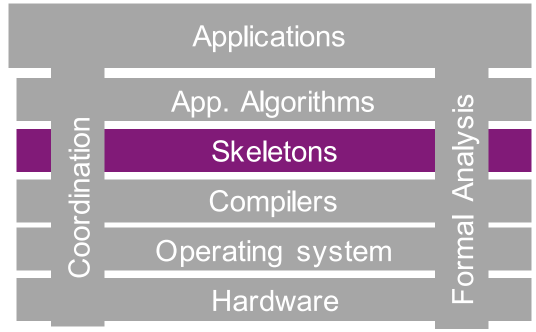


Compilers

- SW synthesis for Tomahawk
  - Static/dynamic mapping
  - Automatic code generation

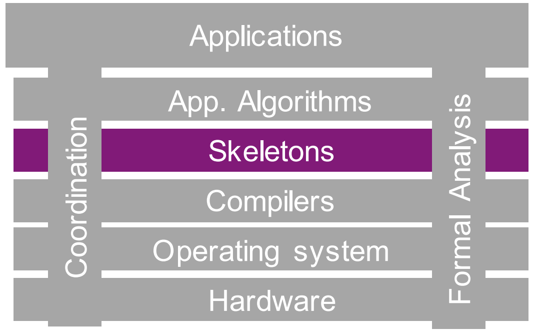




Skeletons

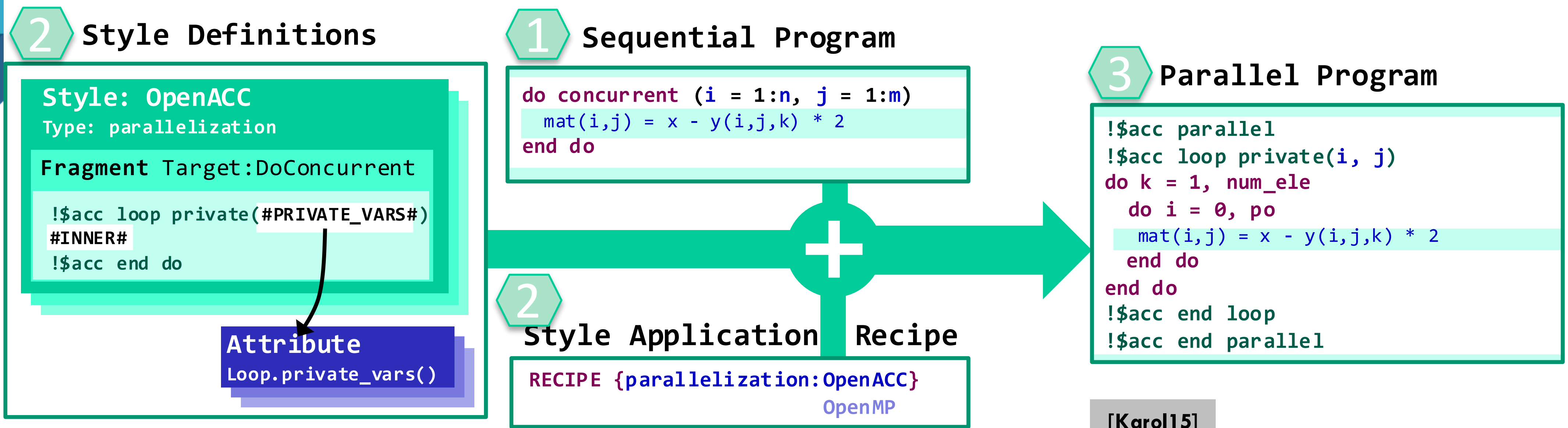
- Basic building blocks for parallelism
- "Heterogeneous" programming
  - Different possible implementations of same principles (CUDA, Fortran, …)
  - Advanced "pre-compiler" to generate and manage variants

  ➔ **Productivity**



Skeletons

- Basic building blocks for parallelism



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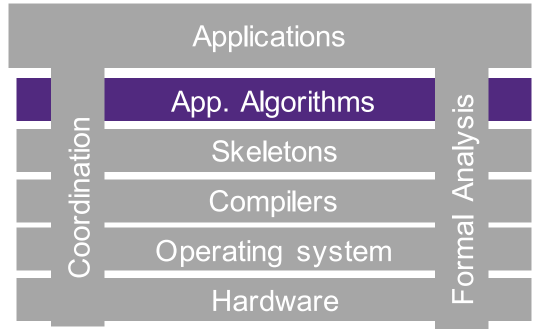
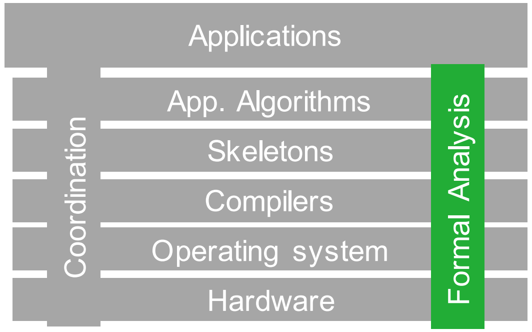


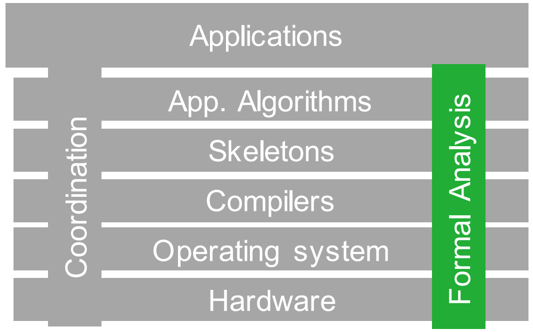
Algorithms

- Raise the level of abstraction
  - High-level **domain specific languages** (more later)
  - Algorithmic transformations: more optimization room
  - Algorithmic specification: allow for adaptability



Formal analysis

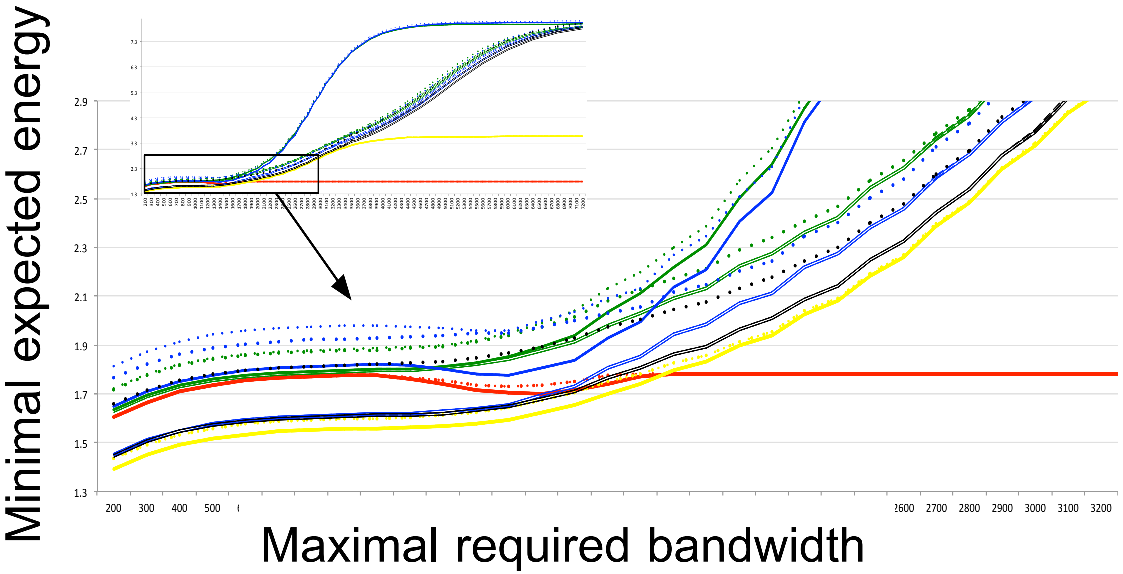
- Probabilistic model checking (PMC)
  - **Analyze** approaches across layers of the stack
  - Work on models for heterogeneous systems
  - Examples:
    - Probability of finishing N tasks in T time
    - Probability of finishing N tasks with energy budget B
    - Trade-off analysis cost-utility (energy vs. performance)
  - Model protocols: Spinlock, barriers, eBond, …



Formal analysis

- Probabilistic model checking (PMC)

eBond



[Baier14]

Outline

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- HW/SW stacks
- Orchestration stack
- **Outlook**
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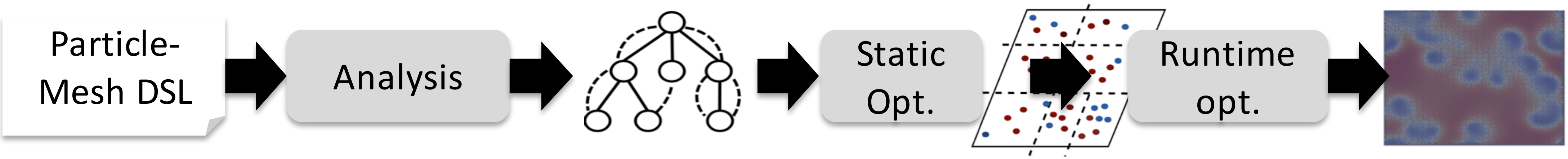
Current and future work

- Further work on languages and methodologies
  - Computational biology
  - Chemical information processing
- Technology analysis at system-level
  - Pros (USPs) and cons
  - Attempt skip incremental improvement
  - System-level benefit based on assumptions

Language for computational biology

- Particle and mesh-based Simulations
  - Discrete models of physical phenomena
- Goal: Abstract programming language + optimization for heterogeneous HPC-clusters



[Karol15]

Language for computational biology

```
client grayscott
  integer, dimension
  real(..), dimensio
  integer

  add_arg(k_rate,<#r
  add_arg(F,<#real(m
  add_arg(D_u,<#real
  add_arg(D_v,<#real

  ppm_init(1)

  U = create_field(1
  V = create_field(1
  topo = create_topo
  c = create_particl

  allocate(displace(
  call random_number
  call c%move(displa
  call c%apply_bc(in

  global_mapping(c,
  discretize(U,c)
  discretize(V,c)
  ghost_mapping(c)

  foreach p in parti
    U_p = 1.0_mk
    V_p = 0.0_mk
    if (((x_p(1)-0.5

      U_p = 0.5_mk
      V_p = 0.25_mk
    end if
  end foreach
```

ArithmeticOperation × | typeof_BinaryExpression × | typeof_AssignmentExpression ×

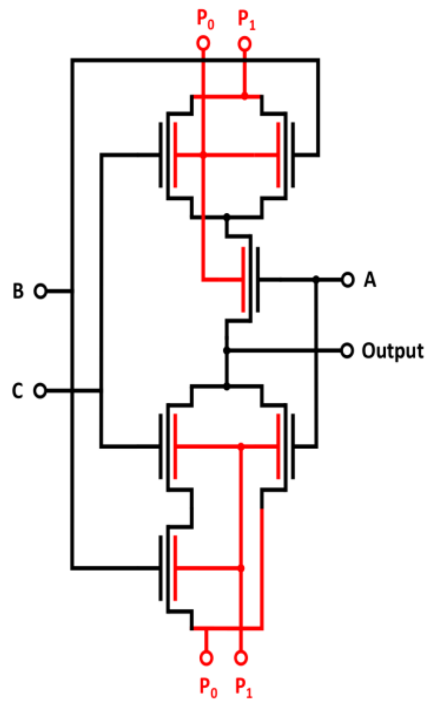
```
import LaplacePSE2D from stencils as Lap
import BcdefPeriodic from topologies as bcdef
import RungeKutta from schemes as rk4

module GrayScott
  external real kRate = 1.0;   "reaction rate"
  external real F;             "reaction parameter"
  external real Du = 1.0;      "diffusion constant of U"
  external real Dv = 1.0;      "diffusion constant of V"

  phase initialize
    << ... >>
  end initialize

  phase solve
    field <real , 1> U;
    field <real , 1> V;
    integer t;

    δU/δt = Du * ∇² U − U * V² + F * (1 − U);
    δV/δt = Dv * ∇² V + U * V² − (F + kRate) * V;
  end solve

  phase finalize
    << ... >>
```

```
_mk  * c%h_avg#>)
.0_mk, 1.0_mk], "Lap")

am_op_dcpse,
der=>2,c=>1.0_mk])

tt_rhs,[U=>c,V],  rk4)

h sca_fields(U,V,dU,dV)
 + F*(1.0_mk-U_p)
 - (F+k_rate)*V_p
```

[Karol15]

SiNW: Components and reconfigurability

- Edge of SiNW over other technologies
  - P/N reconfigurability
  - Multi-gate devices (with low latency penalty)
- Components based on assumptions
  - New uArchitectures?
  - New pipeline structures and compiler optimizations?



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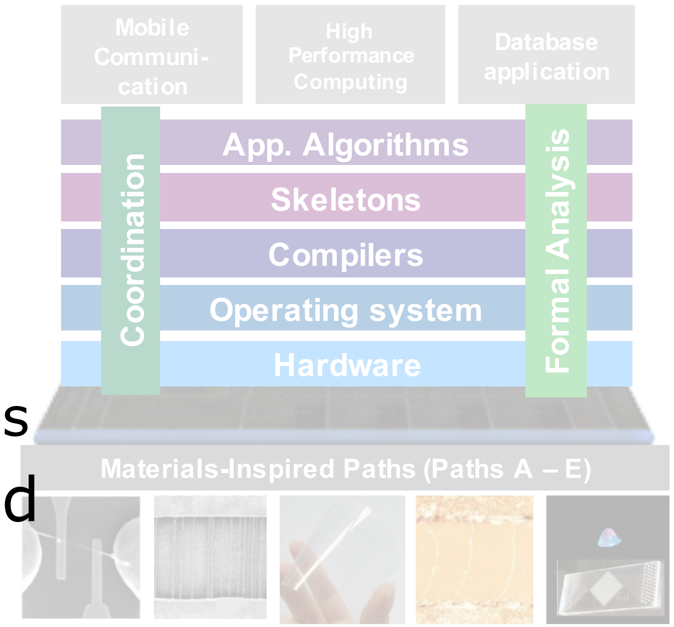
Summary

- Orchestration path: Multi-disciplinary effort to turn **materials breakthroughs** into **application performance**
- HW/SW stack to handle heterogeneity
  - Using CMOS as vehicle
  - Prepare for "*wildly*" heterogeneous systems
- Interact with material experts, understand technologies and analyze at system-level



Thanks!

Retreat: Orchestration and resilience paths (03.2015)

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