Applied Parallel Computing

Ian Ozsvald
ian@morconsulting.com
www.morconsulting.com

Minesh B. Amin
mamin@mbasciences.com
www.mbasciences.com

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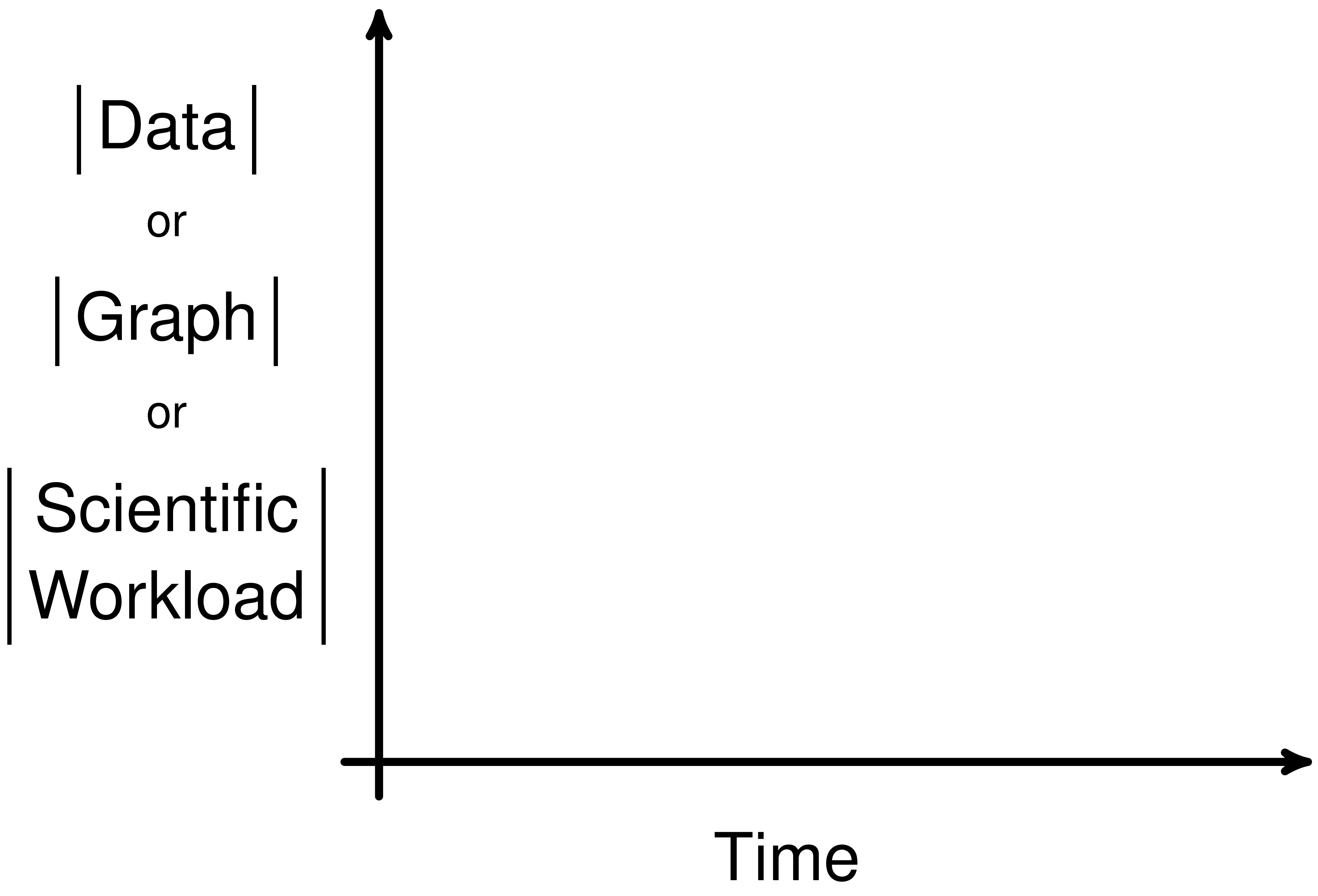
Santa Clara, CA
March 14, 2013

$\left\{\begin{array}{c}\textbf{Robust}\\\textbf{Fault tolerant}\end{array}\right\}$ Parallelism: Why?



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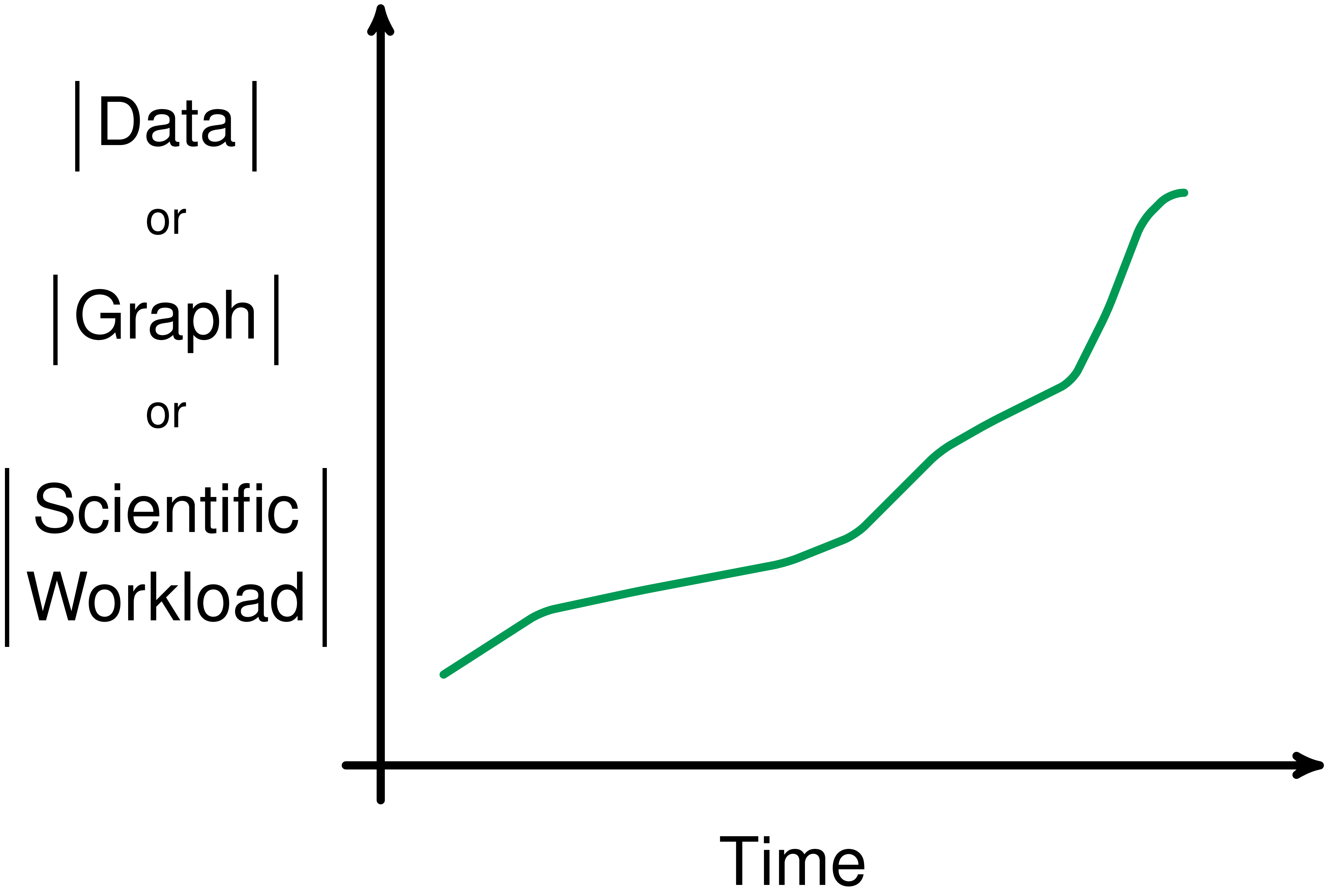
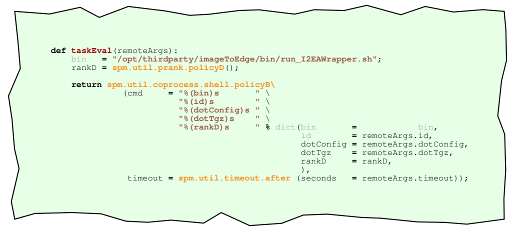


{Robust / Fault tolerant} Parallelism: How (Take I)?

Serial Module



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Robust
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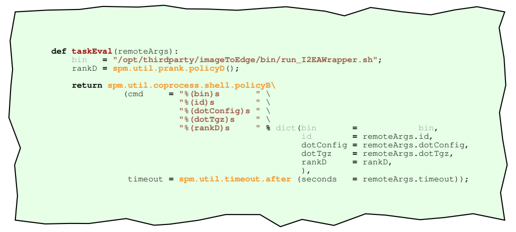

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Multiple
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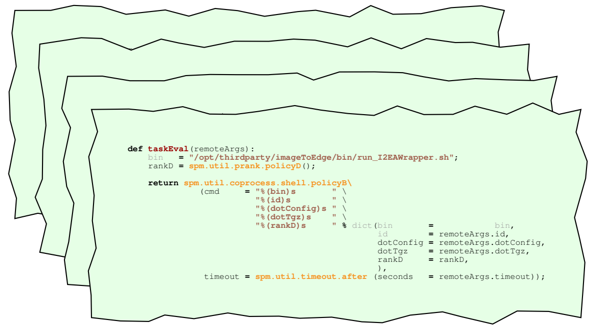

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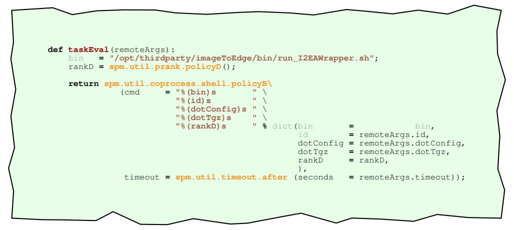

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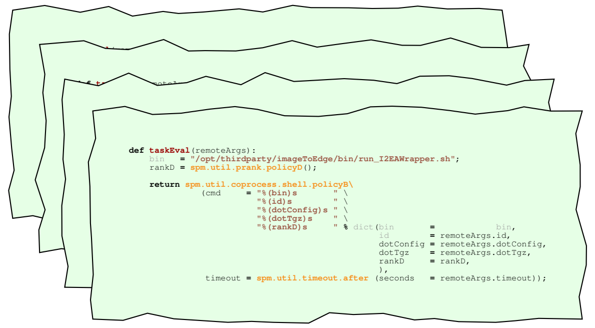

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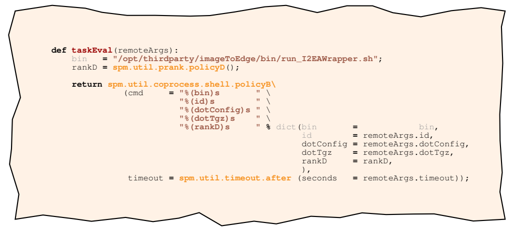

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{ Robust / Fault tolerant } Parallelism: How (Take I)?

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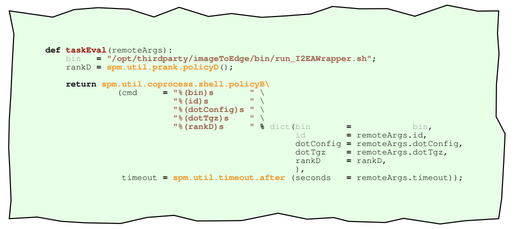

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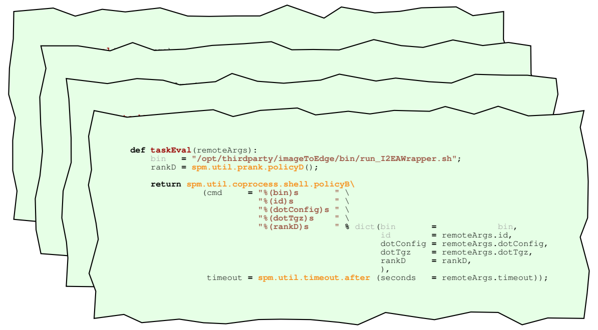

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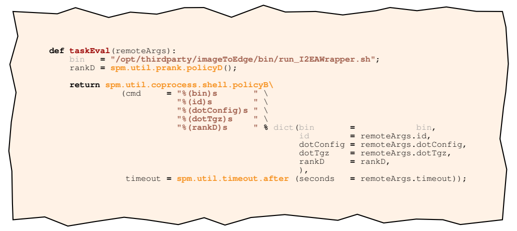

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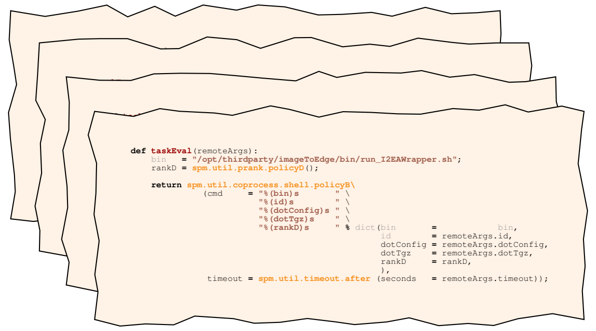

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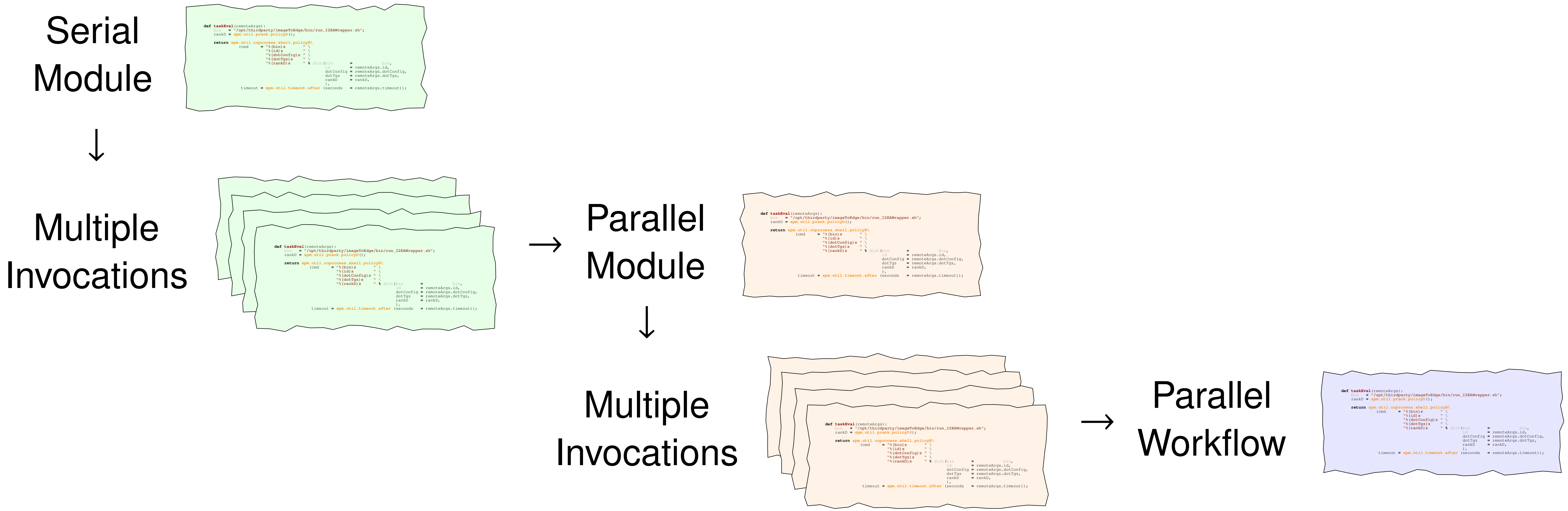
{Robust / Fault tolerant} Parallelism: How (Take I)?



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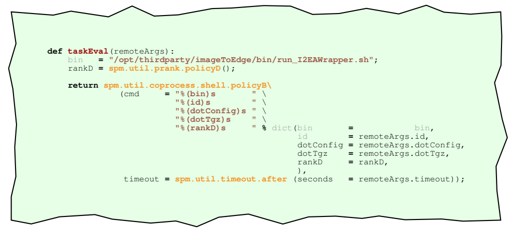

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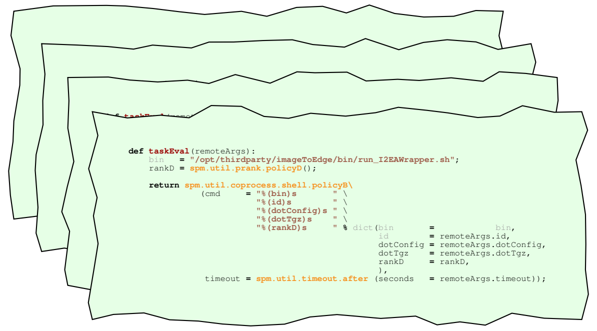

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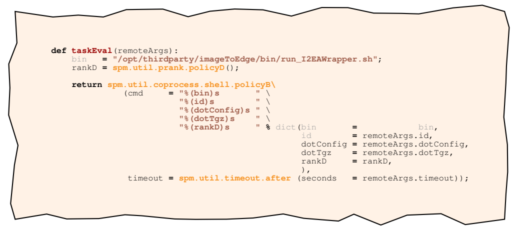

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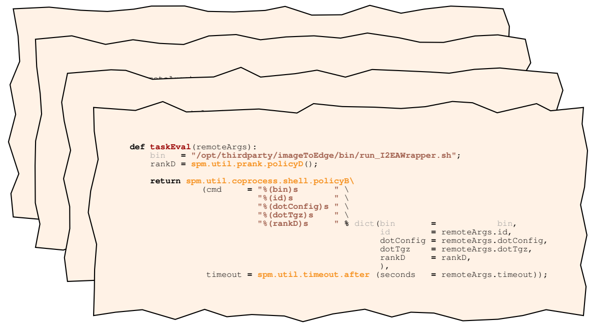

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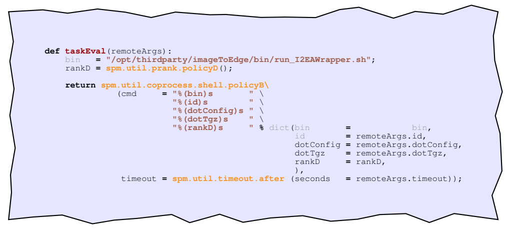
→ Parallel Workflow



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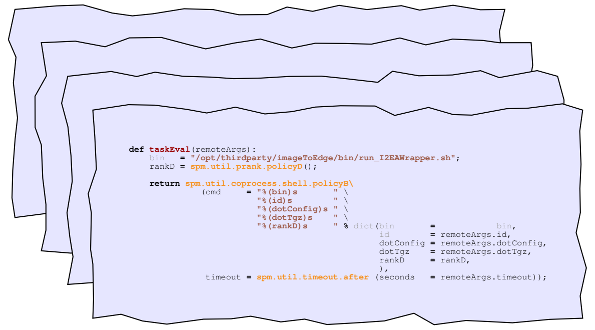

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$\left\{\begin{array}{c}\textbf{Robust}\\ \textbf{Fault tolerant}\end{array}\right\}$ Parallelism: How (Take II)?

> A Language determines the concepts we can think of
>
> - Benjamin Worf

$\left\{\begin{array}{c}\textbf{Robust}\\ \textbf{Fault tolerant}\end{array}\right\}$ Parallelism: How (Take II)?

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$\left\{\begin{array}{c}\textbf{Robust}\\ \textbf{Fault tolerant}\end{array}\right\}$ Parallelism: How (Take II)?

$$\text{A}\left\{\begin{array}{c}\text{Language}\\ \text{Runtime Env}\\ \\ \\ \end{array}\right\}\ \text{determines the concepts we can think of}$$

$\left\{\begin{array}{c}\textbf{Robust}\\ \textbf{Fault tolerant}\end{array}\right\}$ Parallelism: How (Take II)?

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$$\text{A} \left\{\begin{array}{c}\text{Language}\\ \text{Runtime Env}\\ \text{Framework}\\ \text{Library}\end{array}\right\} \text{ determines the concepts we can think of}$$

Preamble: "The Big Picture"

Question: Is exploiting parallelism $\left\{ \begin{array}{c} \text{easy} \\ \text{hard} \end{array} \right\}$?

Preamble: "The Big Picture"

What makes

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Copyright 1994, The UNIX-HATERS Handbook

Preamble: "The Big Picture"

What makes

Question: Is exploiting parallelism $\left\{ \begin{array}{c} \text{~~easy~~} \\ \text{hard} \end{array} \right\}$?

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Supposition: The gap between developer’s intent and API of PET (parallel enabling technologies) ...

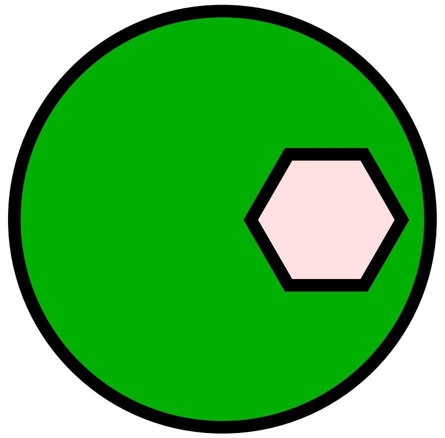
Preamble: "Parallel Enabling Technologies"

Means to the end

- Bottom-up

OpenMPI OpenMP
CUDA OpenGL

- Maximum flexibility
- Maximum headaches
- Must implement fault tolerance



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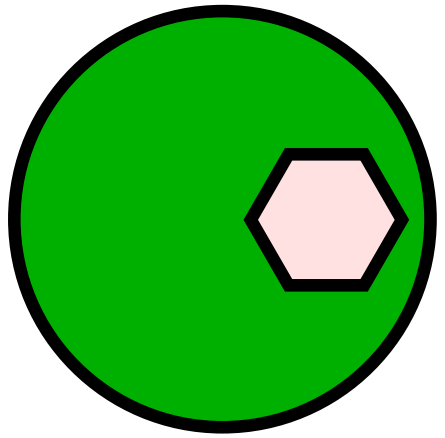
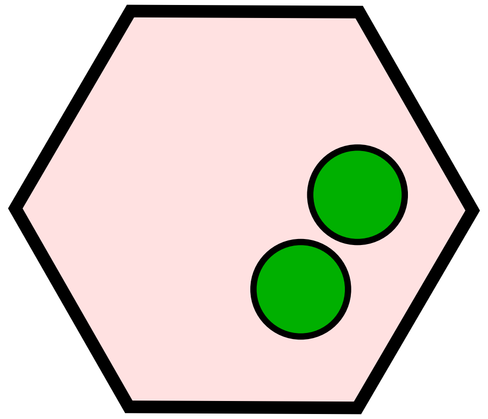


- Top-down

  Hadoop Goldenorb
  GraphLab

  - Limited flexibility
  - Fewer headaches
  - Fault tolerance is inherited



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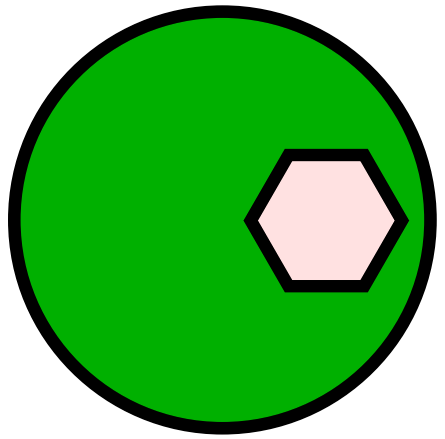

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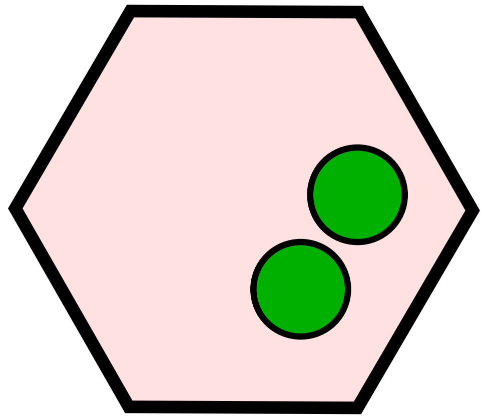

- Self-contained environment

  SPM.Python

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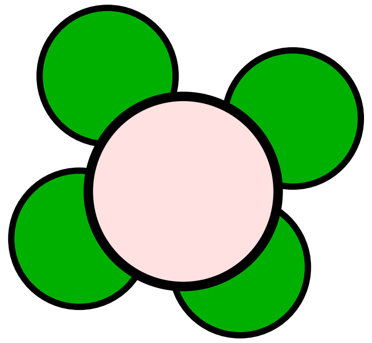

Preamble: "Exploiting Parallelism"

Parallelism: The management of a collection of serial tasks

Management: The policies by which:

- tasks are scheduled,
- premature terminations are handled,
- preemptive support is provided,
- communication primitives are enabled/disabled, and
- the manner in which resources are obtained and released

Serial Tasks: Are classified in terms of either:

- Coarse grain ... where tasks may not communicate prior to conclusion, or
- Fine grain ... where tasks may communicate prior to conclusion.

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Management policies codify how serial tasks are to be managed ... independent of what they may be

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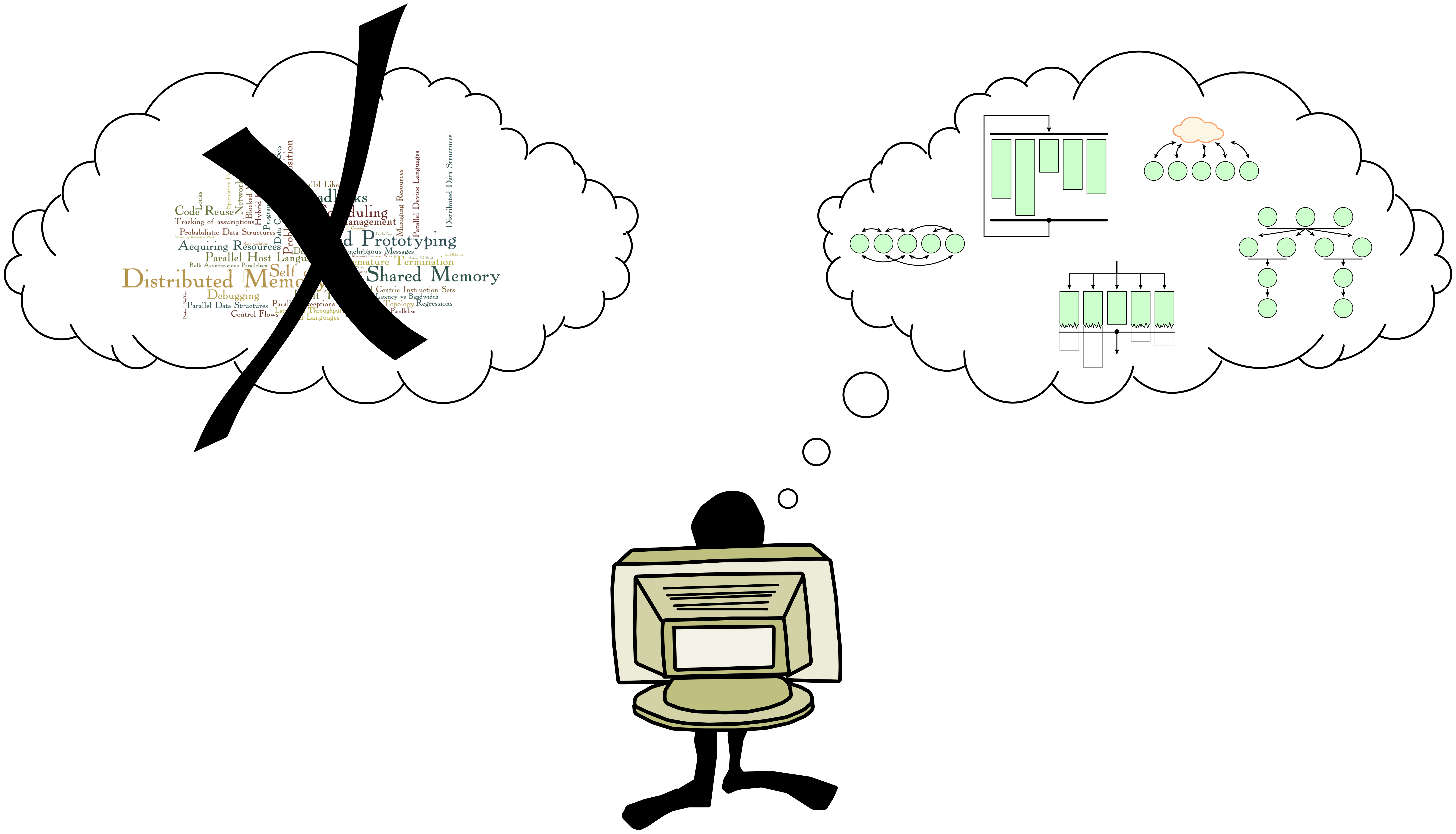
management:

... a more challenging facet of [parallel] software engineering ...

- The Future of Computing Performance: Game Over or Next Level?
National Academy of Sciences, 2011


Distributed Data Structures
Parallel Device Languages
Managing Resources
Locks
Speculative
Code Reuse
Blocked
Hybrid
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Probabilistic Data Structures
Eliminating Redundant Work
Race conditions
Acquiring Resources
Lock-Free
Prototyping
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Minimizing Redundant Work
Asking For Work
Load Balancing
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Throughput
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Languages

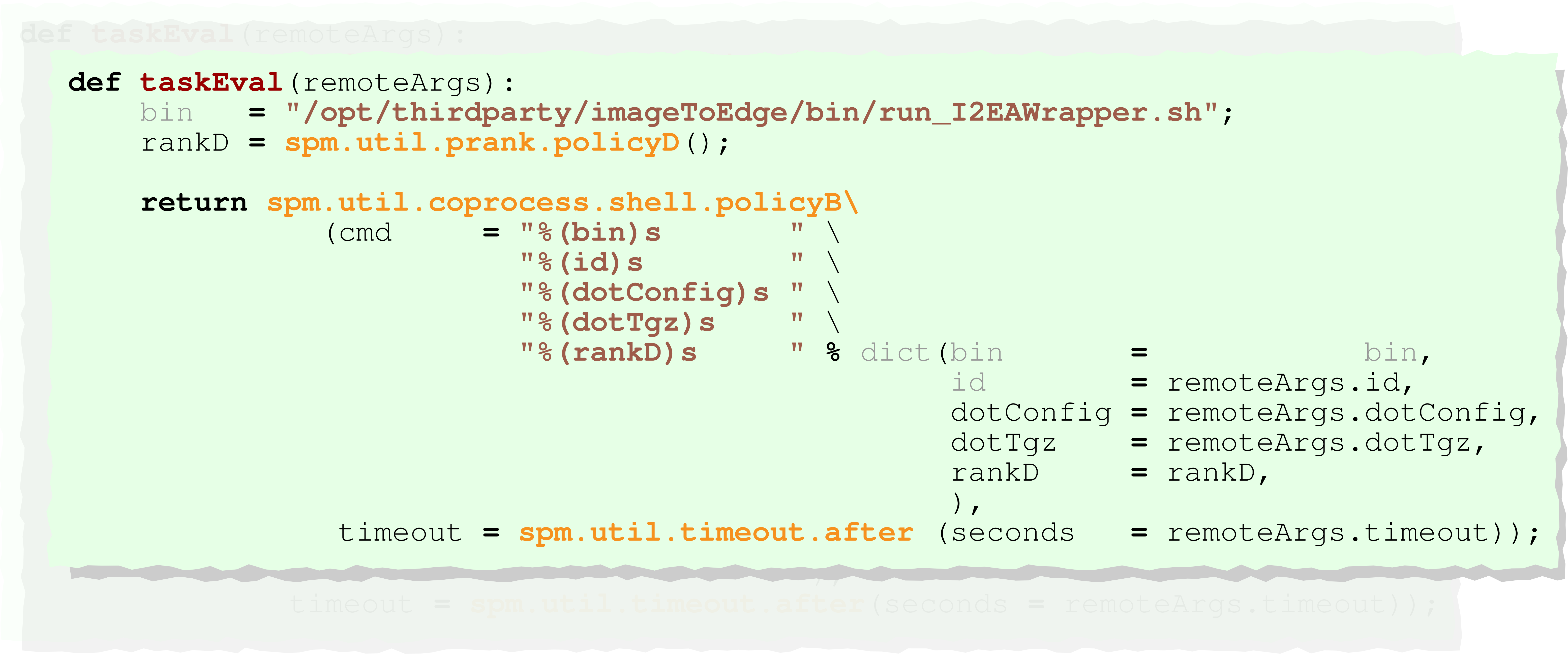
Module (Serial) Module (Parallel) Parallel Workflow

```
def taskEval(remoteArgs):
    return spm.util.coprocess.shell.policyB\
              (cmd     = "%(bin)s  " \
                         "%(v)s    " \
                         "-c %(c)s " \
                         "-d %(d)s " \
                         "-s %(s)s " \
                         "-a %(a)s " \
                         "-o %(o)s " % dict(bin =         remoteArgs.bin,
                                            v   = { True  : ’-v’,
                                                    False : ’’,
                                                    None  : ’’,
                                                    }   [ remoteArgs.v ],
                                            c   =         remoteArgs.c,
                                            d   =         remoteArgs.d,
                                            s   =         remoteArgs.s,
                                            a   =         remoteArgs.a,
                                            o   =         remoteArgs.o,
                                            ),
               timeout = spm.util.timeout.after(seconds = remoteArgs.timeout));
```

Module (Serial)

Module (Parallel)

Parallel Workflow



```
def taskEval(remoteArgs):
    bin   = "/opt/thirdparty/imageToEdge/bin/run_I2EAWrapper.sh";
    rankD = spm.util.prank.policyD();

    return spm.util.coprocess.shell.policyB\
              (cmd      = "%(bin)s         " \
                          "%(id)s          " \
                          "%(dotConfig)s " \
                          "%(dotTgz)s      " \
                          "%(rankD)s       " % dict(bin       =            bin,
                                                    id        = remoteArgs.id,
                                                    dotConfig = remoteArgs.dotConfig,
                                                    dotTgz    = remoteArgs.dotTgz,
                                                    rankD     = rankD,
                                                    ),
               timeout = spm.util.timeout.after (seconds   = remoteArgs.timeout));
```

```
def taskEval(remoteArgs):
                timeout = spm.util.timeout.after(seconds = remoteArgs.timeout));
```

Module (Serial)

Module (Parallel)

Parallel Workflow

```
def main(pool, env):
    submitTask(env                      = env)  \
   .execTask  (pool                     = pool,
               timeoutWaitForSpokes = 2,    # Secs
               timeoutExecution     = 300, # Secs
              );

    if (terminateEarly):
        raise Exception("skysim failed");

@grainCoarseSingleton.pclosure
def submitTask():
    return stdlib.cache(# Core options
                        bin = '...',
                        v   = True,
                        c   = "/nfs/expt100000/dotCConfig.json",
                        d   = "/nfs/expt100000/dotD",
                        s   = "/nfs/expt100000/dotSConfig.json",
                        a   = "/nfs/expt100000/dotAConfig.json",
                        o   = "/nfs/expt100000/output",
                        # Meta options
                        timeout = 300, # Secs
                        label   = "phaseA (exec)",
                        env     = env);
```

Module (Serial)

Module (Parallel)

Parallel Workflow

```
def main(pool, env, batchFile):
    submitTask(env                 = env,
               batchFile            = batchFile) \
   .execTask  (pool                 = pool,
               timeoutWaitForSpokes = 2,    # Secs
               timeoutExecution     = 300, # Secs
              );

    if (terminateEarly):
        raise Exception("imageToEdge failed");

@grainCoarseList.pclosure
def submitTask(env, batchFile):
    rval = [];
    for cmd in filter(len,                 # Skip any empty line ...
                      map((lambda x:
                              x.strip()), # Skip any prefix/suffix spaces ...
                          batchFile.split('\n'))):
        rval += [ stdlib.cache(cmd = cmd,
                               timeout = 2, # Secs
                               label   = "imageToEdge (exec - %(ct)d)" \% dict(ct = len(rval),),
                               ),
                  ];
    return rval;
```

Module (Serial)

Module (Parallel)

Parallel Workflow

```
def main():
    import __hidden__.pool as pool;
    import __hidden__.env  as env;
    import util.phaseA.par as phaseA;
    import util.phaseB.par as phaseB;
    import util.phaseC.par as phaseC;
    import util.phaseD.par as phaseC;

    try:
        pool = pool.interAll();
        env  = env .main    ();

        phaseA            .main(pool = pool, env  = env);
        phaseB            .main(pool = pool, env = env);
        batchFile = phaseC.main(pool = pool, env = env);
        phaseD            .main(pool = pool, env = env, batchFile = batchFile);
    except Exception e:
        ...

    return;
```

Module (Serial)

Module (Parallel)

Parallel Workflow

```
def main():
    import __hidden__.pool as pool;
    import __hidden__.env  as env;
    import util.mc    .par  as mc;

    try:
        pool = pool.interAll();
        env  = env .main    ();

        mc.main(pool = pool, env  = env);
    except Exception e:
        ...

    return;
```

```
def main():

                                              env   = env);
                                              env = env);
                                              env = env);
                                              env = env, batchFile = batchFile);
    except Exception e:
        ...

    return;
```

Module (Parallel): Intra-node

Device-specific Component
(in `Emerald`, C, C++ and `Fortran`)

```
def::api pow2::void <Target = Cuda>      \
                    (var a::matrixA&):
  # wrapper around implementation in C++

def::api pow2::void <Target = X98Cores> \
                    (var a::matrixA&):
  # wrapper around implementation in C
  ...

def::api pow2::void <Target = Serial>    \
                    (var a::matrixA&):
  ...
```

Module (Parallel): Intra-node

Heterogeneous Component
(in Emerald)

```
def::api main::void (dim1::int, dim2::int):
  var a::matrixA[dim1,dim2] = rand;
  var b::matrixB[dim1,dim2] = rand;

  try::concurrent:
    from  ( demo :: explict )  import pow2;

    pow2(a);
    b *= 2.0;
  except:
    raise;

  assert(a::(Cuda == Serial == X86Cores));
  assert(b::(Cuda == Serial));

  from global import result;

  result = a::Cuda;

  return;
```

ice-specific Component
rald, C, C++ and Fortran)

```
::void <Target = Cuda>      \
        (var a::matrixA&):
round implementation in C++

::void <Target = X98Cores> \
        (var a::matrixA&):
round implementation in C


::void <Target = Serial>    \
        (var a::matrixA&):
```

Module (Parallel): Intra-node

Heterogeneous Data Structure
(in Emerald)

```
def::struct myMatrix (nDim1 :: int,
                      nDim2 :: int):
  - @ -::Array
    Domain = (nDim1, nDim2);
    Format = Row;
    Target = (::CUDA, ::Serial, ::X86Cores);
  - @ -
  {
    float _;
  };
```

ous Component
merald)

```
d (dim1::int, dim2::int):
im1,dim2] = rand;
im1,dim2] = rand;


   from  ( demo :: explict )  import pow2;

   pow2(a);
   b *= 2.0;
 except:
   raise;

 assert(a::(Cuda == Serial == X86Cores));
 assert(b::(Cuda == Serial));

 from global import result;

 result = a::Cuda;

 return;
```

ice-specific Component
rald, C, C++ and Fortran)

```
::void <Target = Cuda>      \
        (var a::matrixA&):
round implementation in C++

::void <Target = X98Cores> \
        (var a::matrixA&):
round implementation in C


::void <Target = Serial>    \
        (var a::matrixA&):
```

Suppositions

Most embarrassingly parallel solutions
perform a lot of redundant work ...

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Most embarrassingly parallel solutions
perform a lot of redundant work ...

$$\Downarrow$$

- Only fix ... share knowledge

Suppositions

Many problems in HPC and Analytics are memory bounded ...

Suppositions

Many problems in HPC and Analytics are memory bounded ...

$$\Downarrow$$

- Cannot depend on virtualization
- Must throw everything at the problem

Suppositions: Constraints When Exploiting Parallelism

Prototypes
vs
Runtime Env

Suppositions: Constraints When Exploiting Parallelism

Prototypes → Construct-by-correction

vs

Runtime Env

Suppositions: Constraints When Exploiting Parallelism

Prototypes → Construct-by-correction

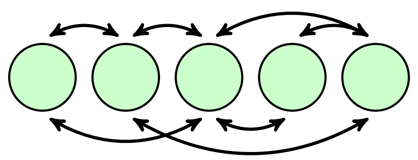
vs

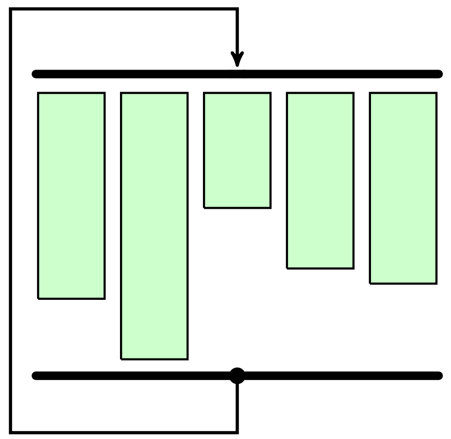
Runtime Env → Correct-by-construction

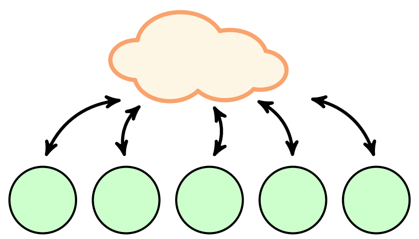
Suppositions: Enabling / Disabling Communication Primitives

SendRecvA(...)

+



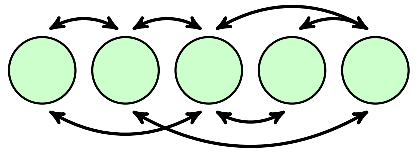




Suppositions: Enabling / Disabling Communication Primitives

SendRecvA(...)

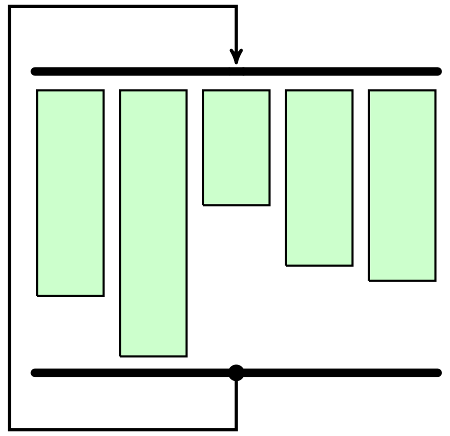
+

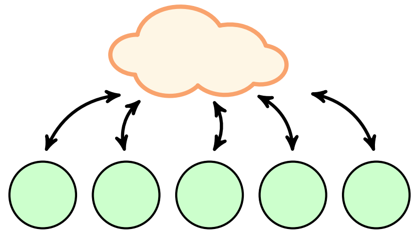


⇓

No

Deadlocks

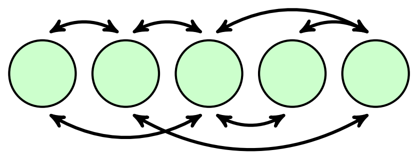


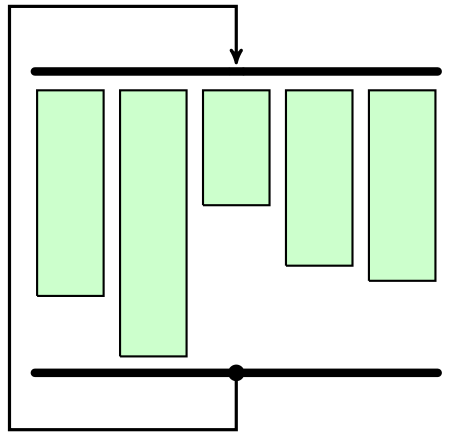


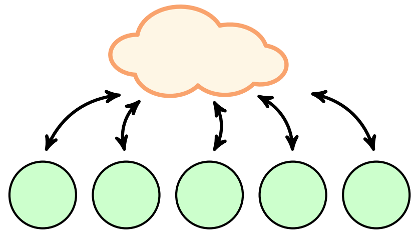
Suppositions: Enabling / Disabling Communication Primitives

SendRecvA(...)

+







⇓

No

Deadlocks

⇓

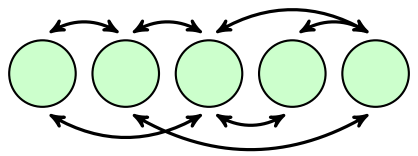
Rare

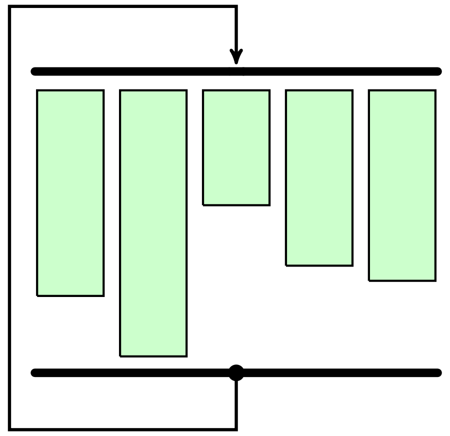
Deadlocks

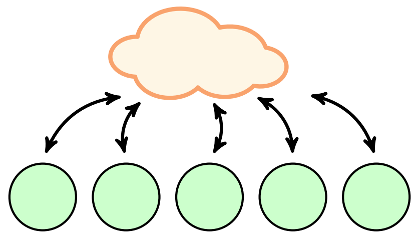
Suppositions: Enabling / Disabling Communication Primitives

SendRecvA(...)

+







⇓
No
Deadlocks

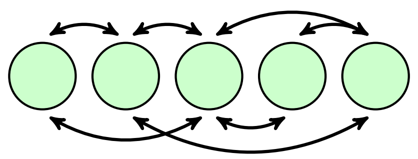
⇓
Rare
Deadlocks

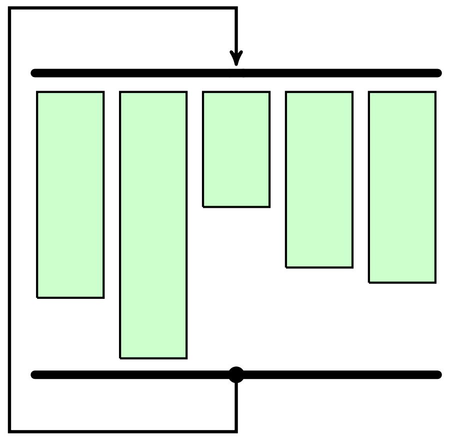
⇓
Frequent
Deadlocks

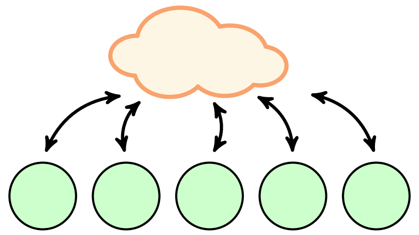
Suppositions: Parallel Semantics

division by zero

+



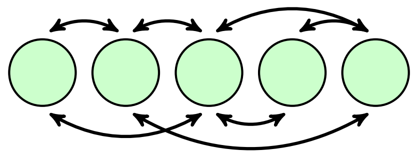


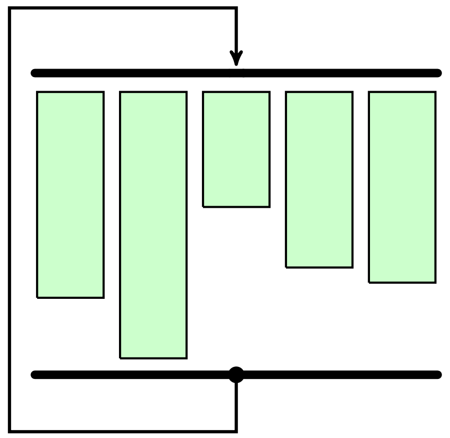


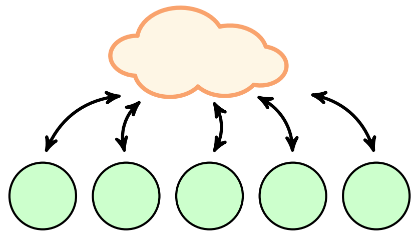
Suppositions: Parallel Semantics

division by zero

+







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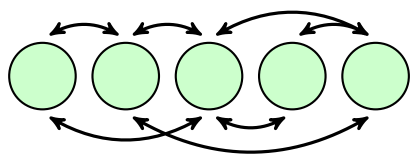
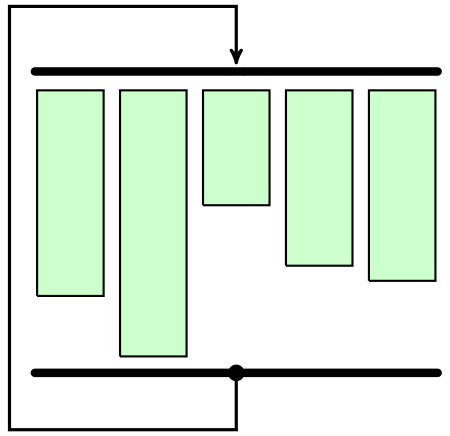
No
Side-effects

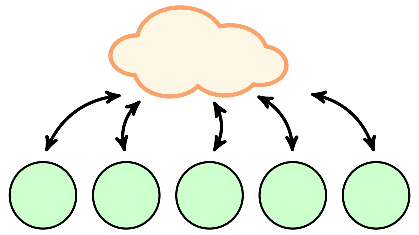
Suppositions: Parallel Semantics

division by zero

+







⇓

No Side-effects

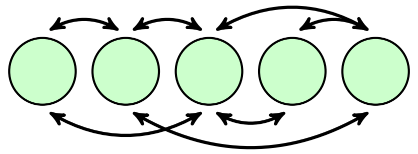
⇓

Global Termination

Suppositions: Parallel Semantics

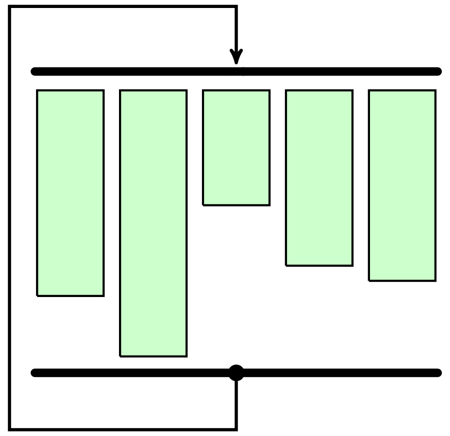
division by zero

+



⇓

No
Side-effects



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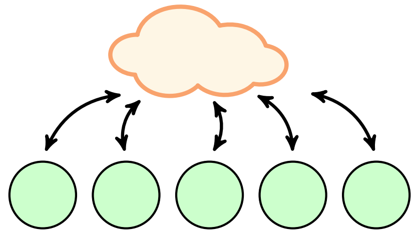
Global
Termination



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Pruning of
pending work

Conclusion: Rest of the tutorial

For each form of parallelism to be reviewed:

- What is the management policy?
- Describe a compatible communication primitive
- Describe a toxic communication primitive