SWARM Tutorial

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Outline

- Introduction to SWARM
- Programming in SWARM
- Atomic Operations in SWARM
- Parallel For Loop in SWARM

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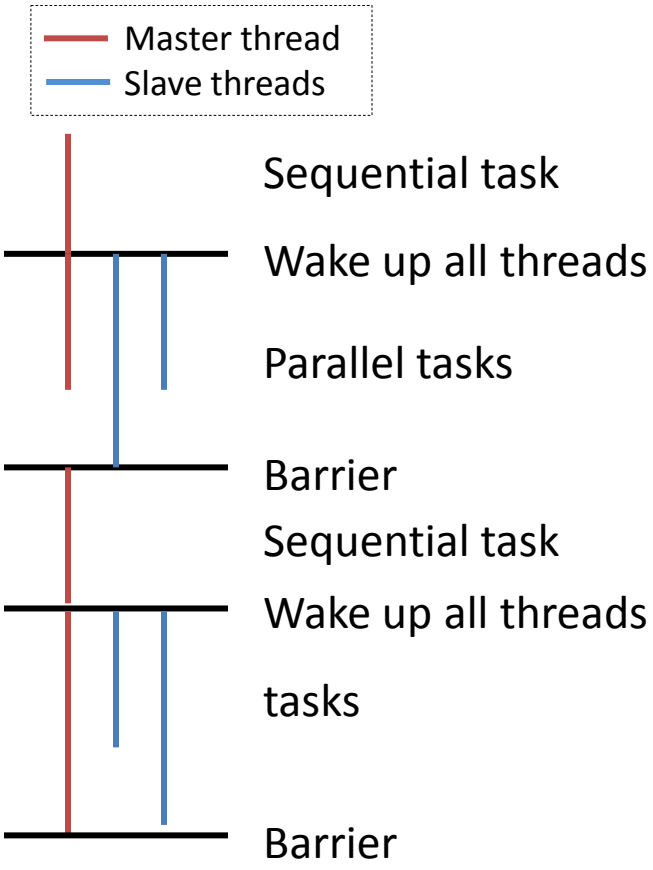
- **Introduction to SWARM**
- Programming in SWARM
- Atomic Operations in SWARM
- Parallel For Loop in SWARM

What is SWARM

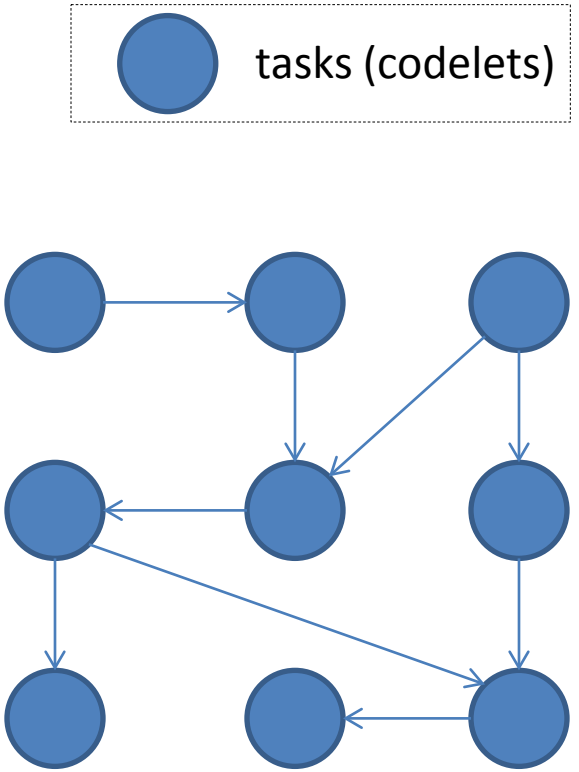
- SWARM (SWift Adaptive Runtime Machine)
- A **dynamic adaptive runtime system** that minimizes user exposure to physical parallelism and system complexity
- SWARM is designed to enable programming on many-core architectures by utilizing a **dynamic, message-driven model** of execution instead of the static scheduling and sequential computing method of conventional programming models

Cited from ETI SWARM webpage, http://www.etinternational.com/index.php/products/swarmbeta/

Difference Between OpenMP and SWARM



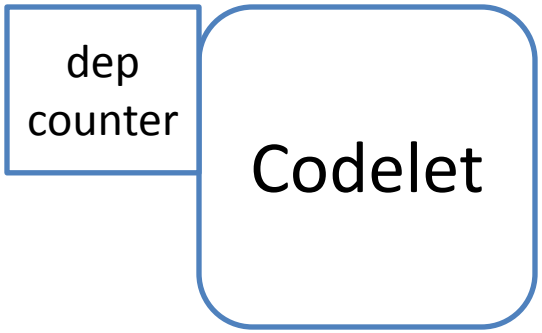
OpenMP
Coarse-grain execution model



SWARM
Fine-grain execution model

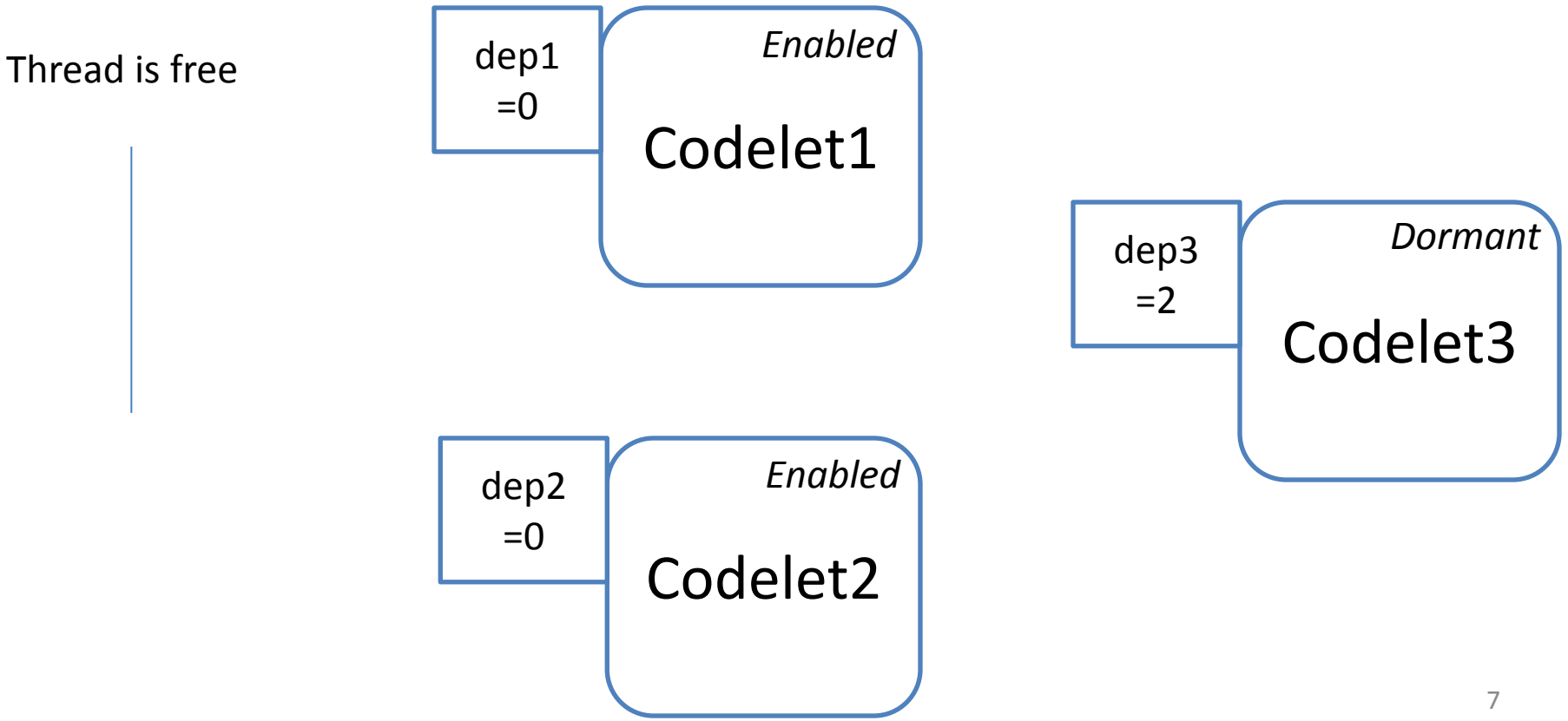
How Codelets Work in SWARM

- Each codelet is attached a dependency counter with some initial positive value
- A codelet is in *dormant* state if its counter is greater than 0
- A codelet is in *enabled* state if its counter is 0
- An *enabled* codelet will be scheduled to a free thread and executed (*firing state*)
- A codelet can call *satisfy()* to decrease the value of any dependency counter
- SWARM runtime handles codelet schedule and dependency maintenance



How Codelet Works in SWARM – an Example

Suppose we have 3 codelets. Codelet3 cannot start unless both codelet1 and codelet2 are done. And suppose we use one thread to execute the 3 codelets.



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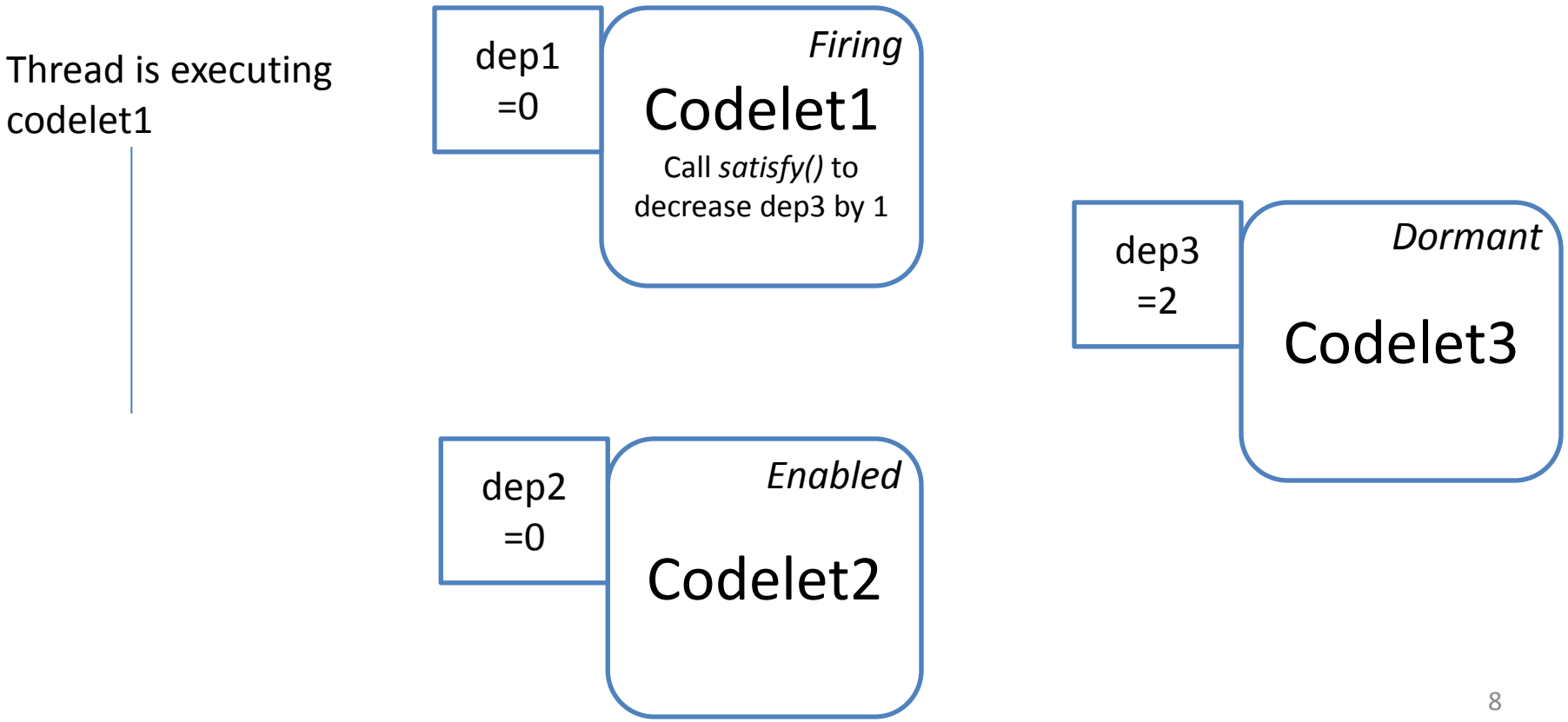

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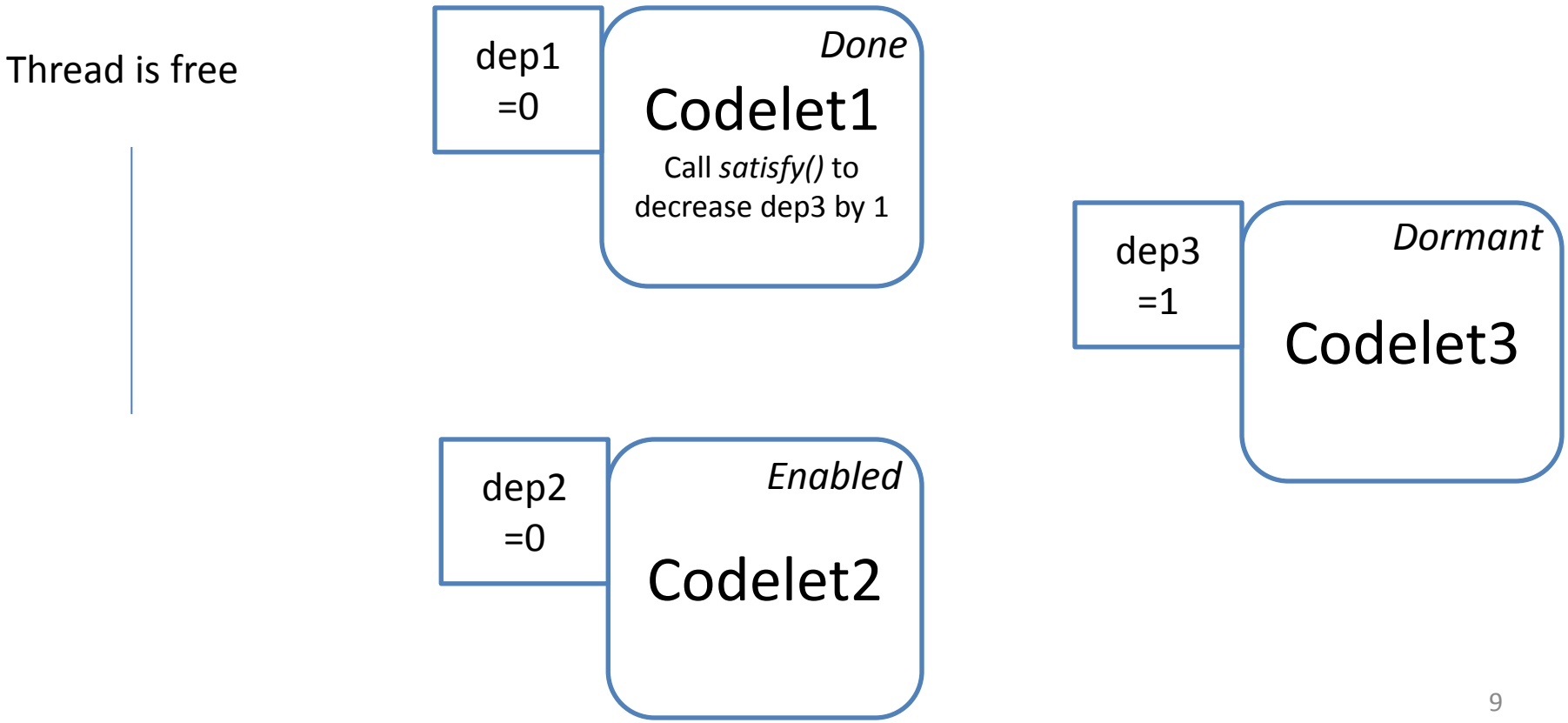

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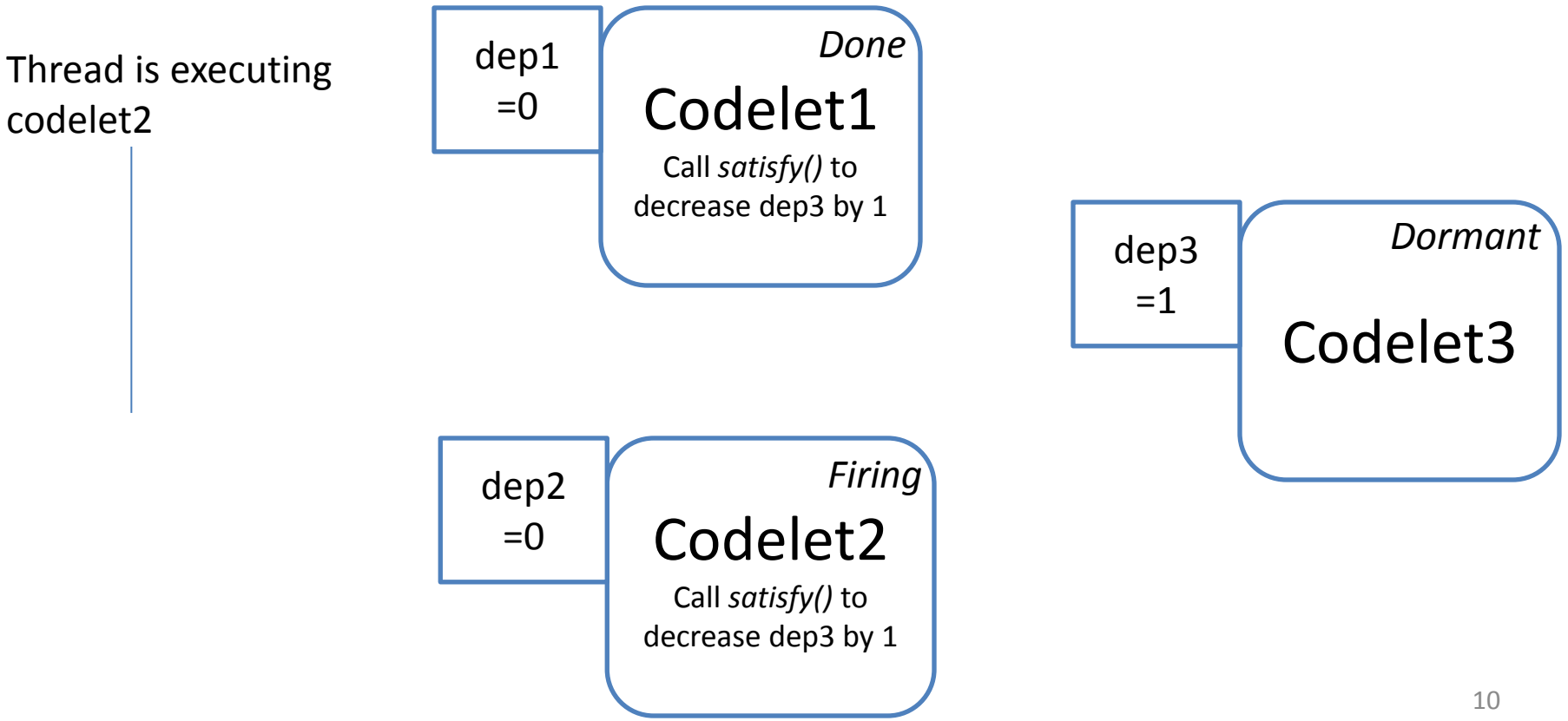

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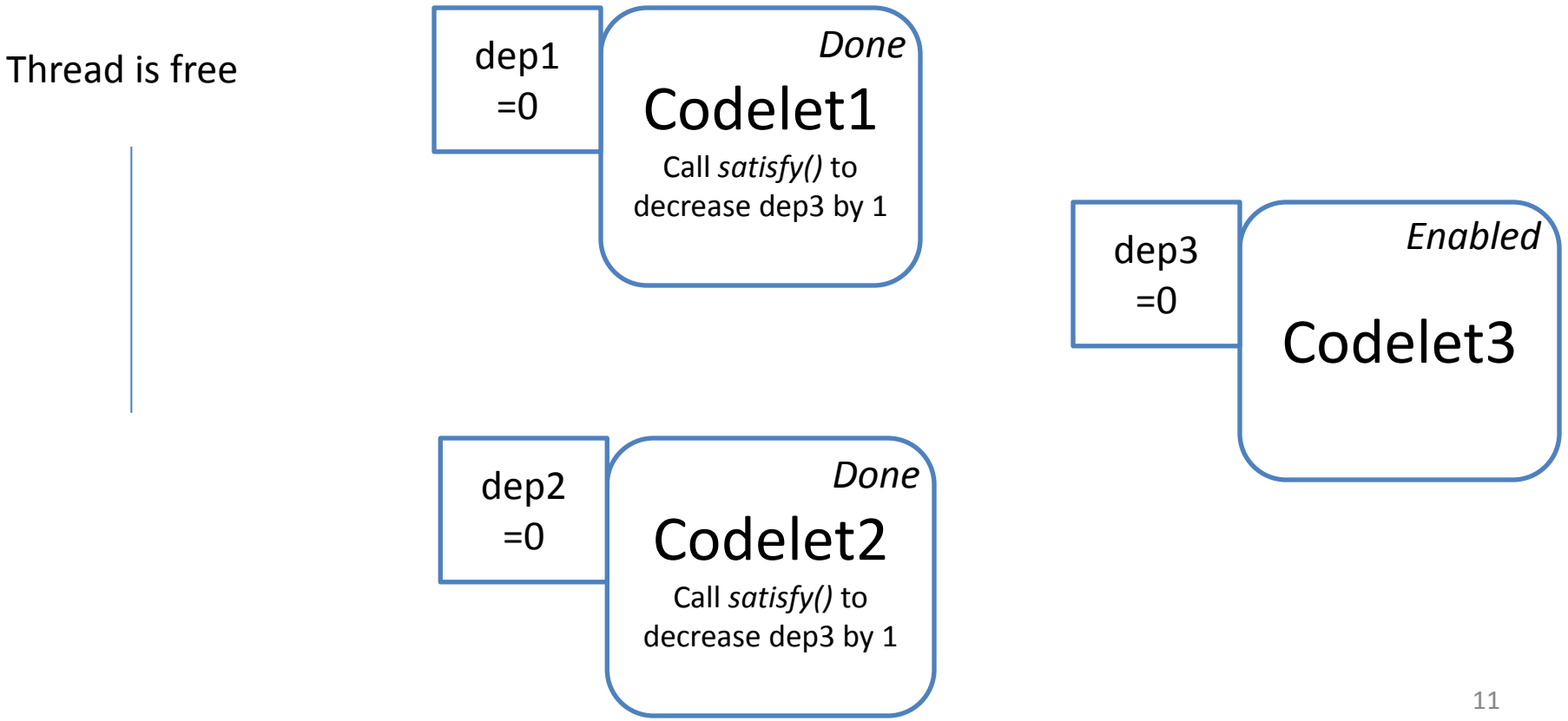

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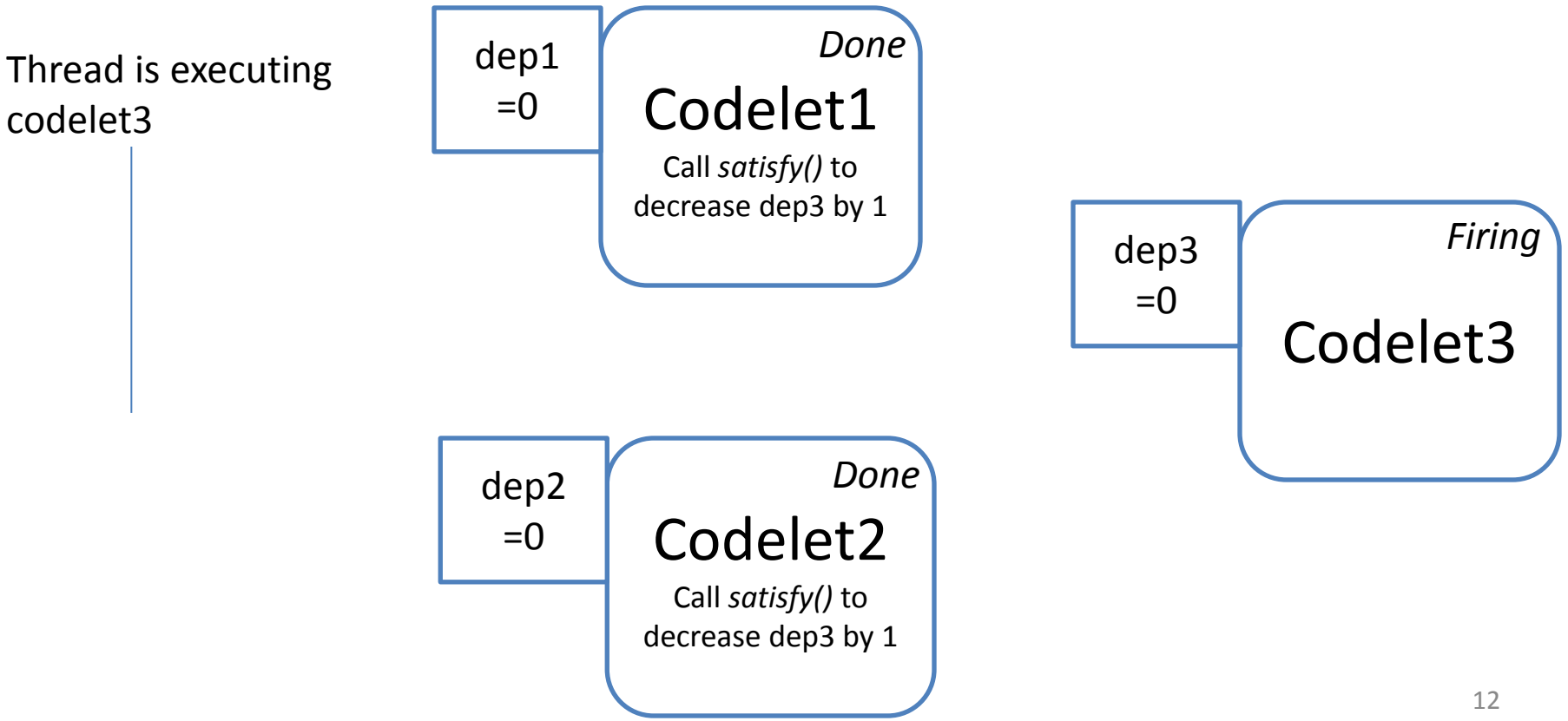

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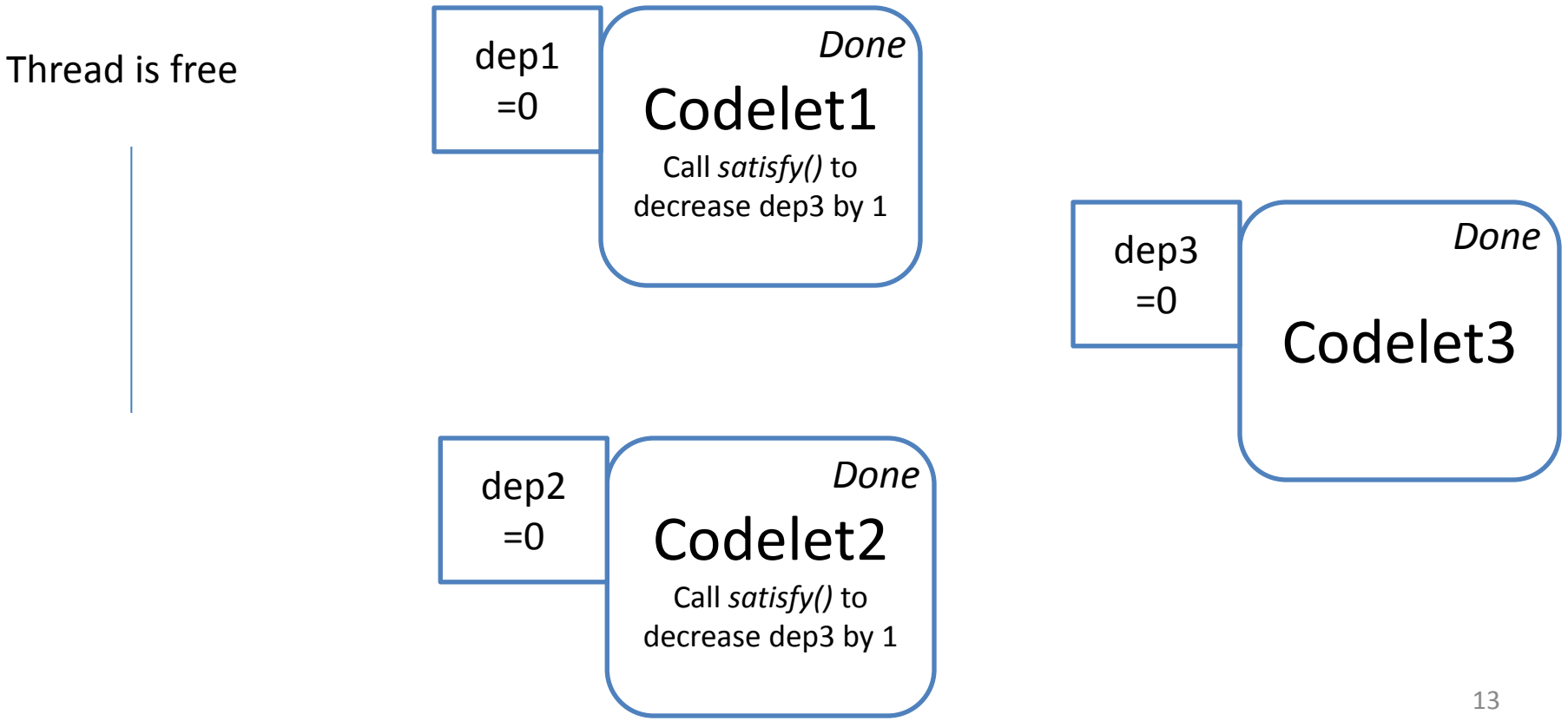

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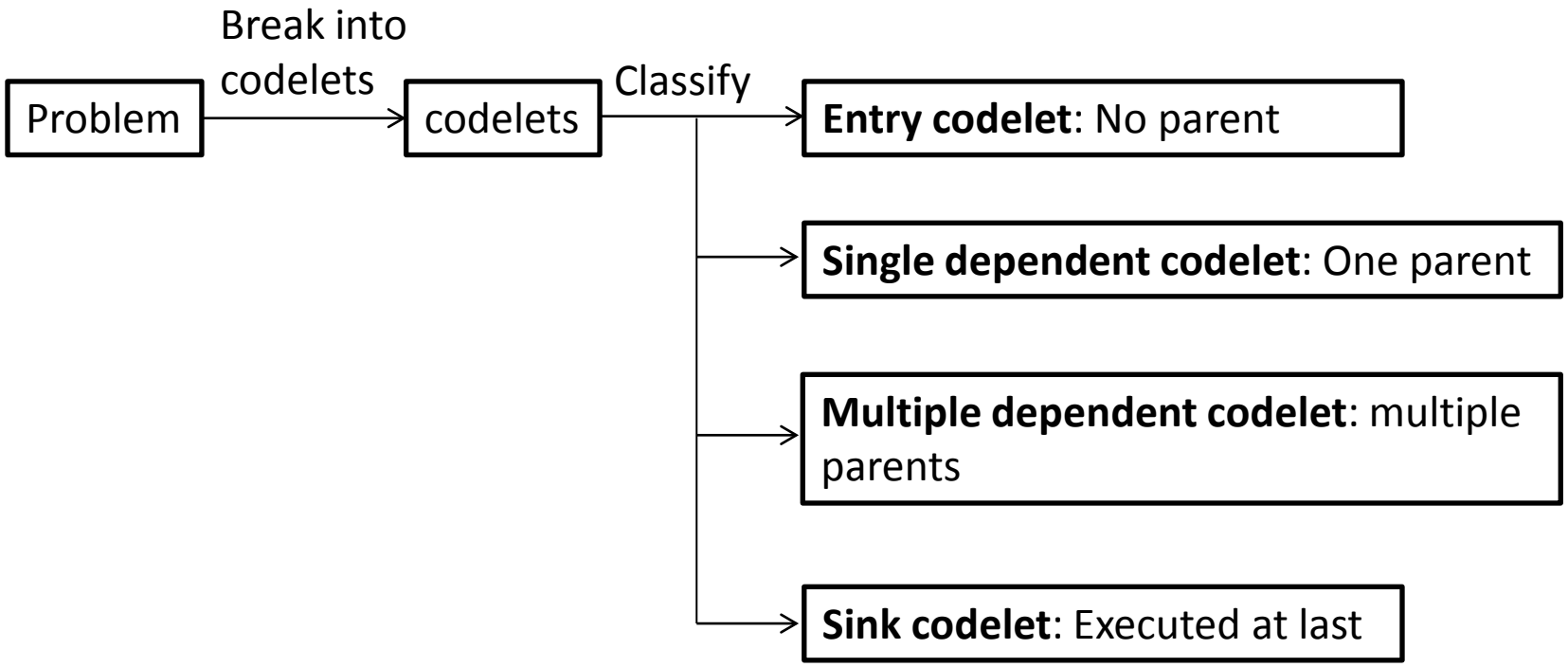
- **Programming in SWARM**
- Atomic Operations in SWARM
- Parallel For Loop in SWARM

Programming in SWARM

Partition the problem into codelets



Programming in SWARM cont.

Setup dependency in the program

Call *swarm_enterRuntime()* to start **entry codelet**

Entry codelet has no parent. We execute it at beginning of SWARM runtime.

Programming in SWARM cont.

Setup dependency in the program

Call *swarm_enterRuntime()* to start **entry codelet**

Call *swarm_scheduleGeneral()* to create a **single dependent codelet** at the end of its parent

Single dependent codelet has only one parent. We create it at the end of its parent without setting dependency.

Programming in SWARM cont.

Setup dependency in the program

Call *swarm_enterRuntime()* to start **entry codelet**

Call *swarm_scheduleGeneral()* to create a **single dependent codelet** at the end of its parent

Call *swarm_dependency_init()* to create a **multiple dependent codelet** before any of its parent is created (e.g., create it at some ancient of all its parents) and setup dependencies

A **multiple dependent codelet** has multiple parents. We have to create it and set its dependency counter. We perform the creation and setting before the start of any of its parents to avoid conflicts in the dependency counter.

Programming in SWARM cont.

Setup dependency in the program

Call *swarm_enterRuntime()* to start **entry codelet**

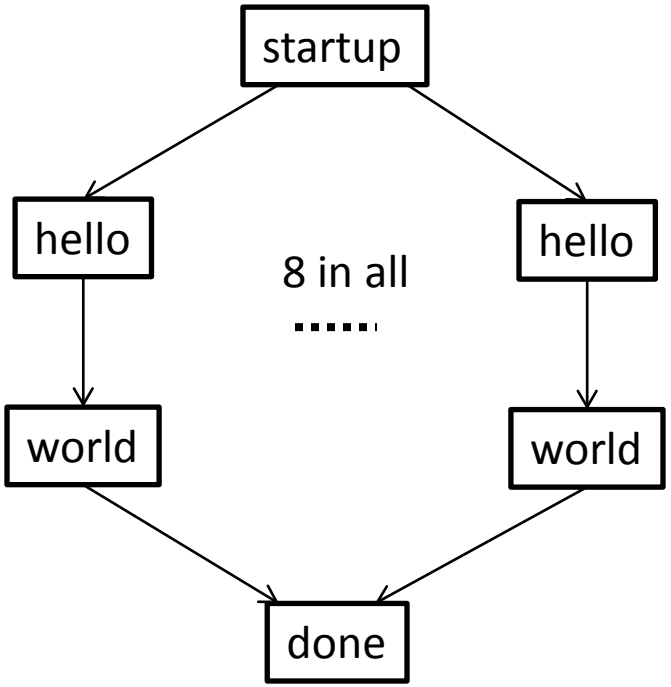
Call *swarm_scheduleGeneral()* to create a **single dependent codelet** at the end of its parent

Call *swarm_dependency_init()* to create a **multiple dependent codelet** before any of its parent is created (e.g., create it at some ancient of all its parents) and setup dependencies

Sink codelet is created in the same way as either **single dependent codelet** or **multiple dependent codelet** , according to the number of its parents

Call *swarm_shutdownRuntime()* at the end of **sink codelet** to terminate SWARM runtime.

Example: Hello World



Codelet graph of hello world

Example: Hello World

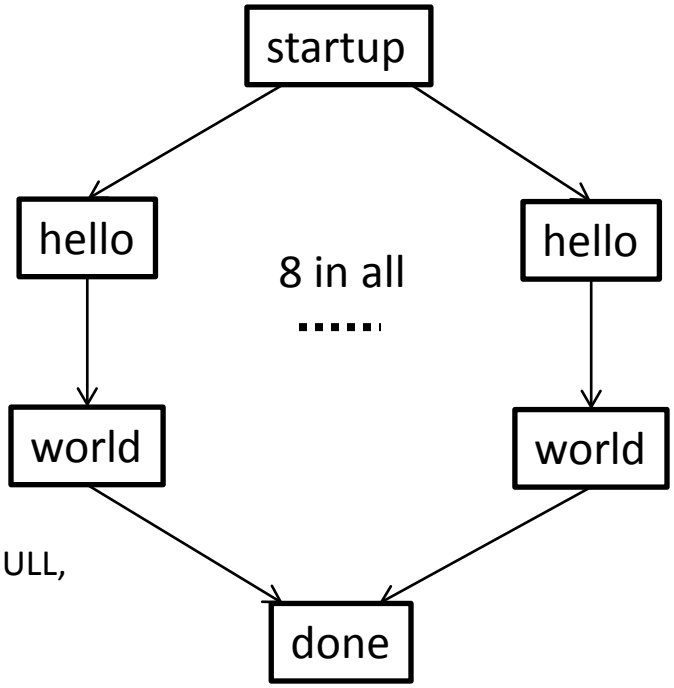
```
#include <stdio.h>
#include <swarm/Runtime.h>
#include <swarm/Scheduler.h>

#define COUNT 8

static void startup(void *);
static void hello(void *);
static void world(void *);
static void done(void *);
int main(void)
{
   return !swarm_enterRuntime(NULL,
                startup, NULL);
}

static swarm_dependency_t dep;
static void startup(void *unused)
{
   unsigned i;
   (void)unused;

   swarm_dependency_init(&dep, COUNT, done, NULL);
   for(i=0; i<COUNT; i++)
      swarm_scheduleGeneral(hello, (void *)(size_t)i);
}
```




```
static void hello(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: Hello,\n", i);
   swarm_scheduleGeneral(world, _i);
}

static void world(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: world!\n", i);
   swarm_satisfy(&dep, 1);
}

static void done(void *unused)
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   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
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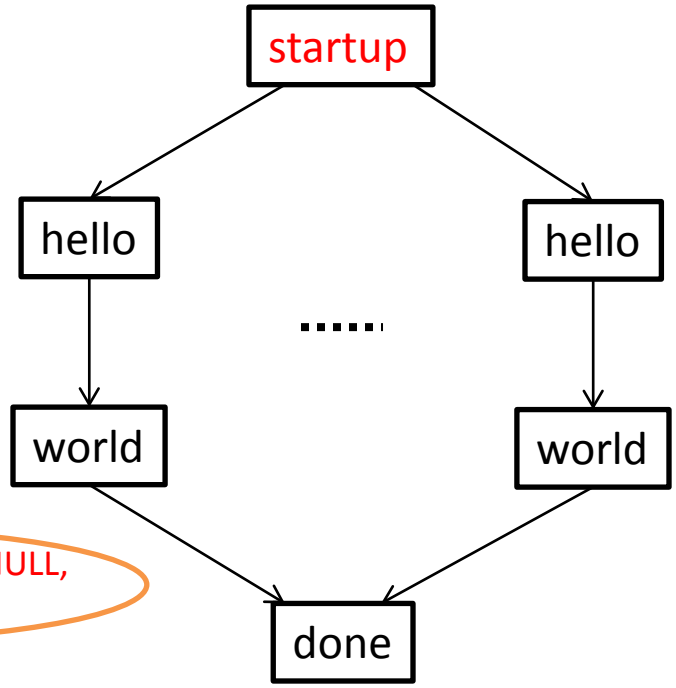


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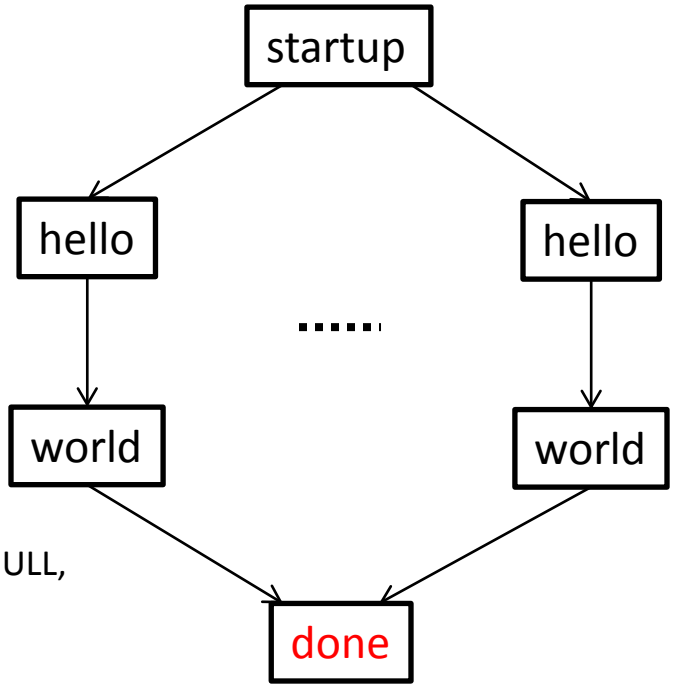


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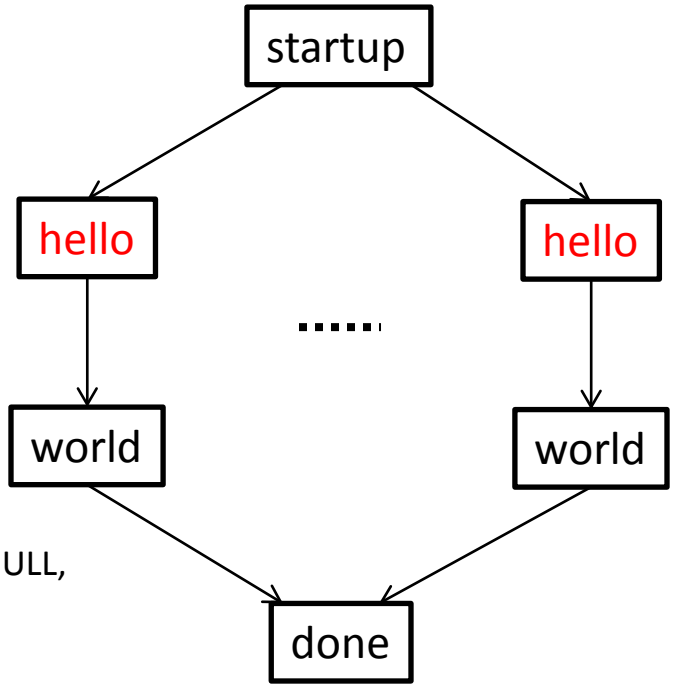


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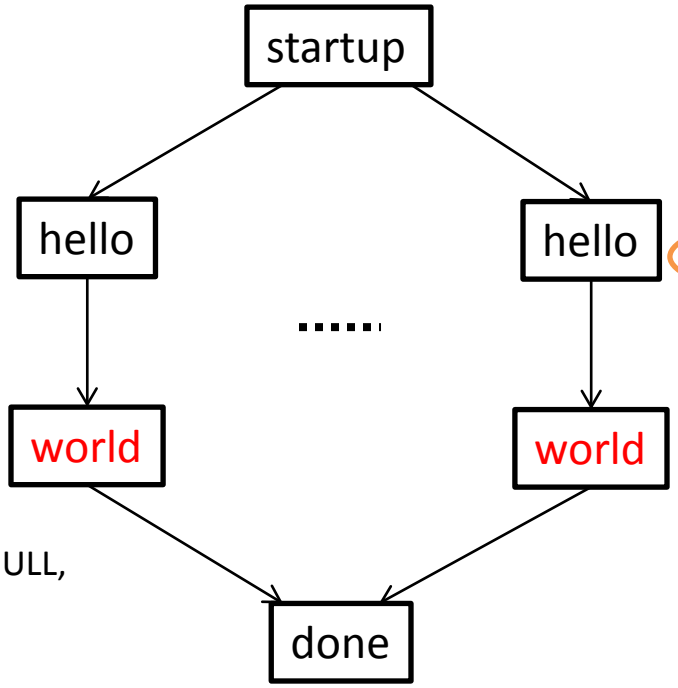


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   printf("%u: Hello,\n", i);
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}

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   const unsigned i = (size_t)_i;

   printf("%u: world!\n", i);
   swarm_satisfy(&dep, 1);
}

static void done(void *unused)
{
   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
}
```

SWARM APIs – Enter SWARM Runtime

- swarm_enterRuntime(*params*, *codelet*, *context*)
  - *params*: pointer to swarm_Runtime_params_t
    - Setting up SWARM runtime (e.g., max number of threads)
  - *codelet*: function name (codelet)
    - Function in the format “void fname(void * context)”
    - Entry codelet
  - *context*: pointer to a data structure
    - The parameters passed to the codelet

Review Hello World

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#include <stdio.h>
#include <swarm/Runtime.h>
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#define COUNT 8

static void startup(void *);
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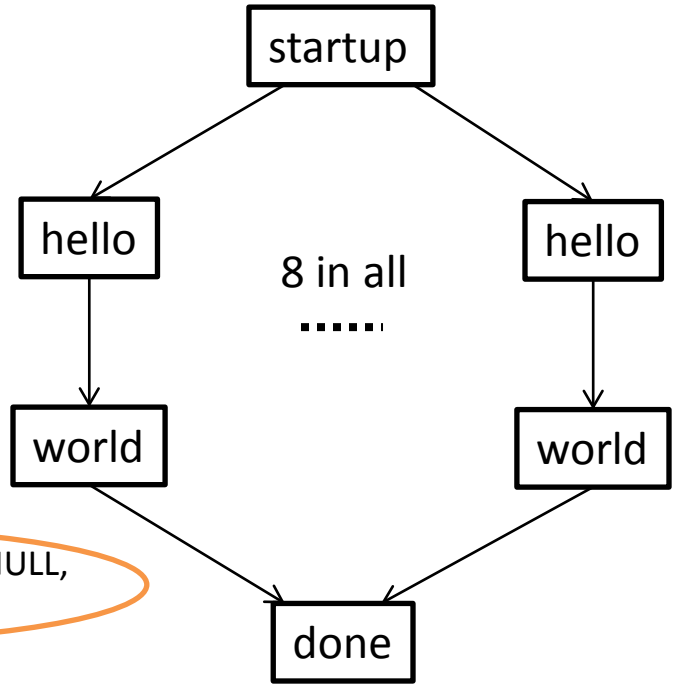


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static void hello(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: Hello,\n", i);
   swarm_scheduleGeneral(world, _i);
}

static void world(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: world!\n", i);
   swarm_satisfy(&dep, 1);
}

static void done(void *unused)
{
   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
}
```

SWARM APIs – Codelet Creation (1)

- Create a free codelet, i.e., the codelet does not depend on other codelets
  - swarm_scheduleGeneral(*codelet*, *context*)
    - *codelet*: function name (codelet)
      - Function in the format “void fname(void * context)”
    - *context*: pointer to a data structure
      - The parameters passed to the codelet

Review Hello World

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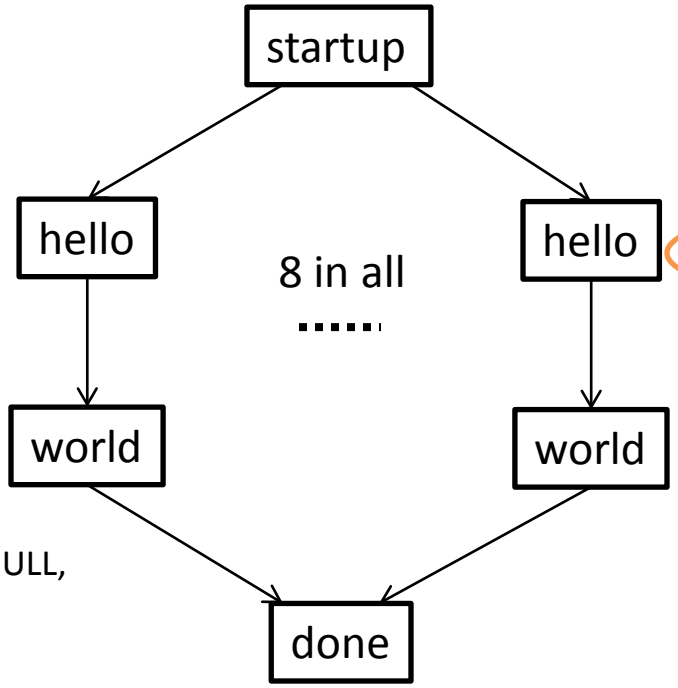


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}

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   const unsigned i = (size_t)_i;

   printf("%u: world!\n", i);
   swarm_satisfy(&dep, 1);
}

static void done(void *unused)
{
   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
}
```

SWARM APIs – Codelet Creation (2)

- Create a dependent codelet, i.e., the codelet depends on other codelets
  - swarm_dependency_init(*dep*, *count*, *codelet*, *context*)
    - *dep*: pointer to swarm_dependency_t
      - A variable that stores number of satisfied dependencies
    - *count*: An integer that specifies required dependencies
    - *codelet*: function name (codelet)
      - Function in the format “void fname(void * context)”
    - *context*: pointer to a data structure
      - The parameters passed to the codelet

Review Hello World

```
#include <stdio.h>
#include <swarm/Runtime.h>
#include <swarm/Scheduler.h>

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static void world(void *);
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}

static swarm_dependency_t dep;
static void startup(void *unused)
{
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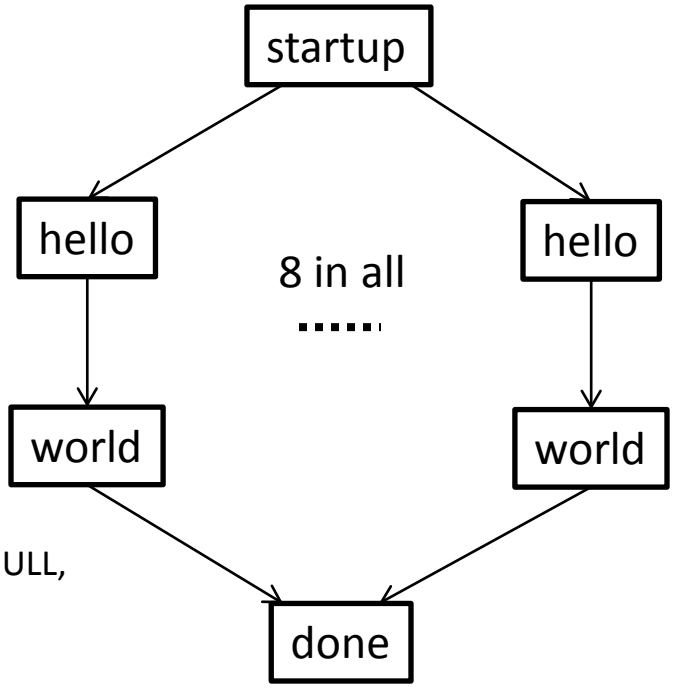


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   const unsigned i = (size_t)_i;

   printf("%u: Hello,\n", i);
   swarm_scheduleGeneral(world, _i);
}

static void world(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: world!\n", i);
   swarm_satisfy(&dep, 1);
}

static void done(void *unused)
{
   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
}
```

SWARM APIs – Satisfy a Dependency

- swarm_satisfy(*dep*, *num*)
  - *dep*: pointer to swarm_dependency_t
    - A variable that stores number of satisfied dependencies
  - *num*: An integer that specifies the number of times to satisfy *dep*

Review Hello World

```
#include <stdio.h>
#include <swarm/Runtime.h>
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#define COUNT 8

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static void hello(void *);
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}

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static void startup(void *unused)
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   unsigned i;
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   swarm_dependency_init(&dep, COUNT, done, NULL);
   for(i=0; i<COUNT; i++)
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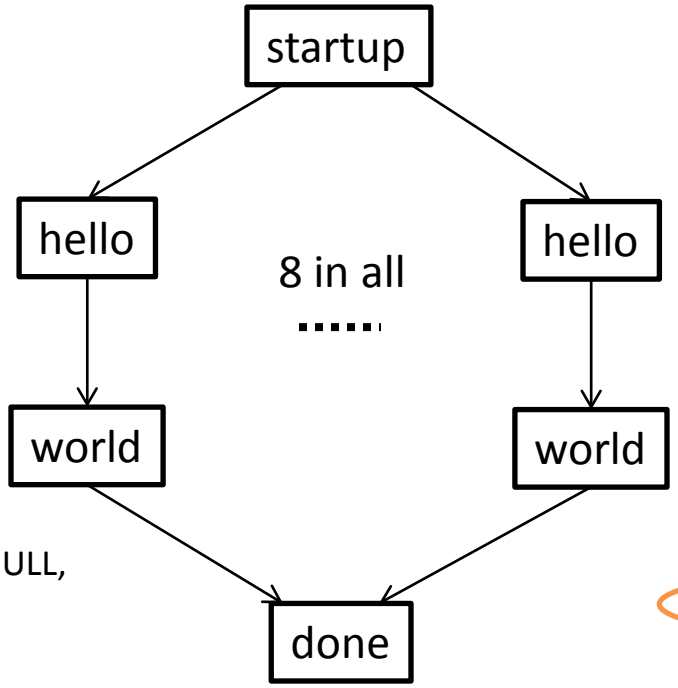


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}

static void done(void *unused)
{
   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
}
```

SWARM APIs – Terminate SWARM Runtime

- swarm_shutdownRuntime(*NULL*)
  - Shut down the runtime in which the caller is executing

Review Hello World

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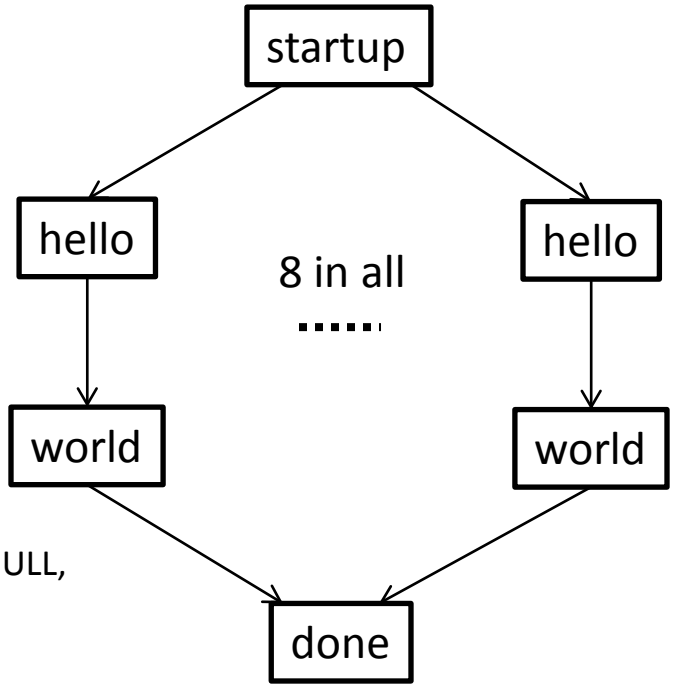
}
```




```
static void hello(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: Hello,\n", i);
   swarm_scheduleGeneral(world, _i);
}

static void world(void *_i)
{
   const unsigned i = (size_t)_i;

   printf("%u: world!\n", i);
   swarm_satisfy(&dep, 1);
}

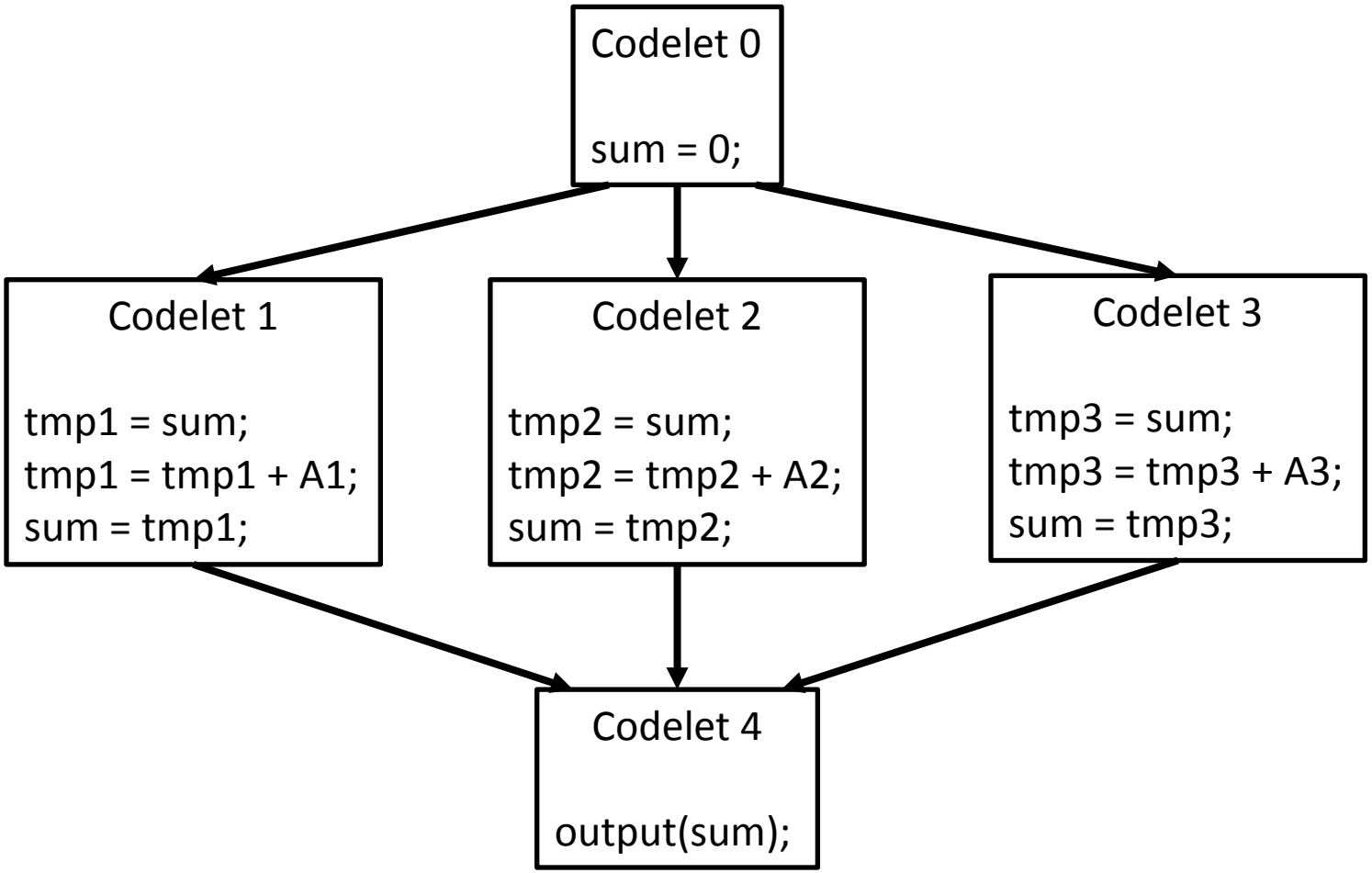
static void done(void *unused)
{
   (void)unused;
   puts("All done!");
   swarm_shutdownRuntime(NULL);
}
```

Outline

- Introduction to SWARM
- Programming in SWARM
- **Atomic Operations in SWARM**
- Parallel For Loop in SWARM

Example: Data Race in Computing Sum

Compute sum = A1 + A2 + A3

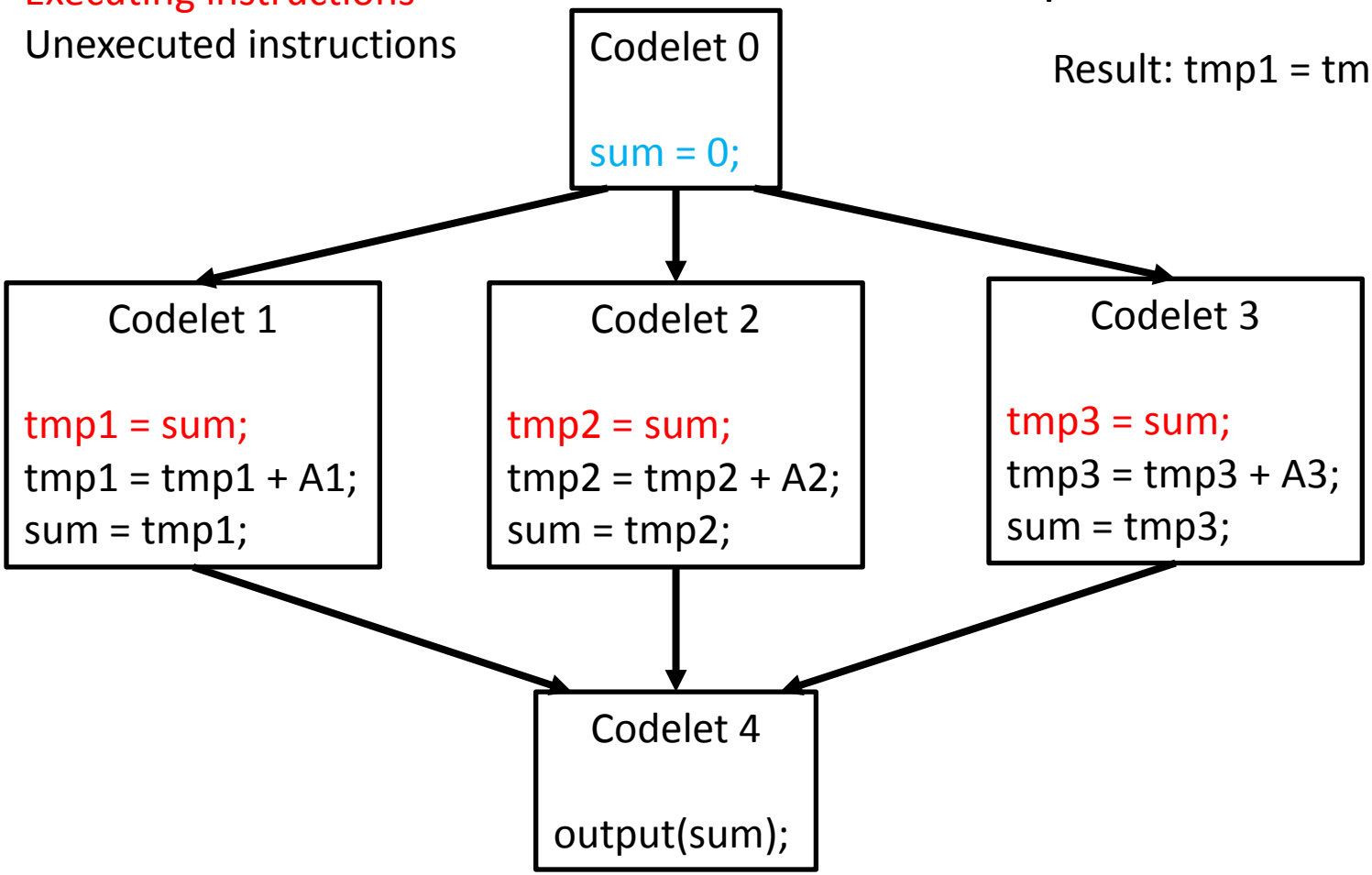


Example: Data Race in Computing Sum

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Result: tmp1 = tmp2 = tmp3 = 0

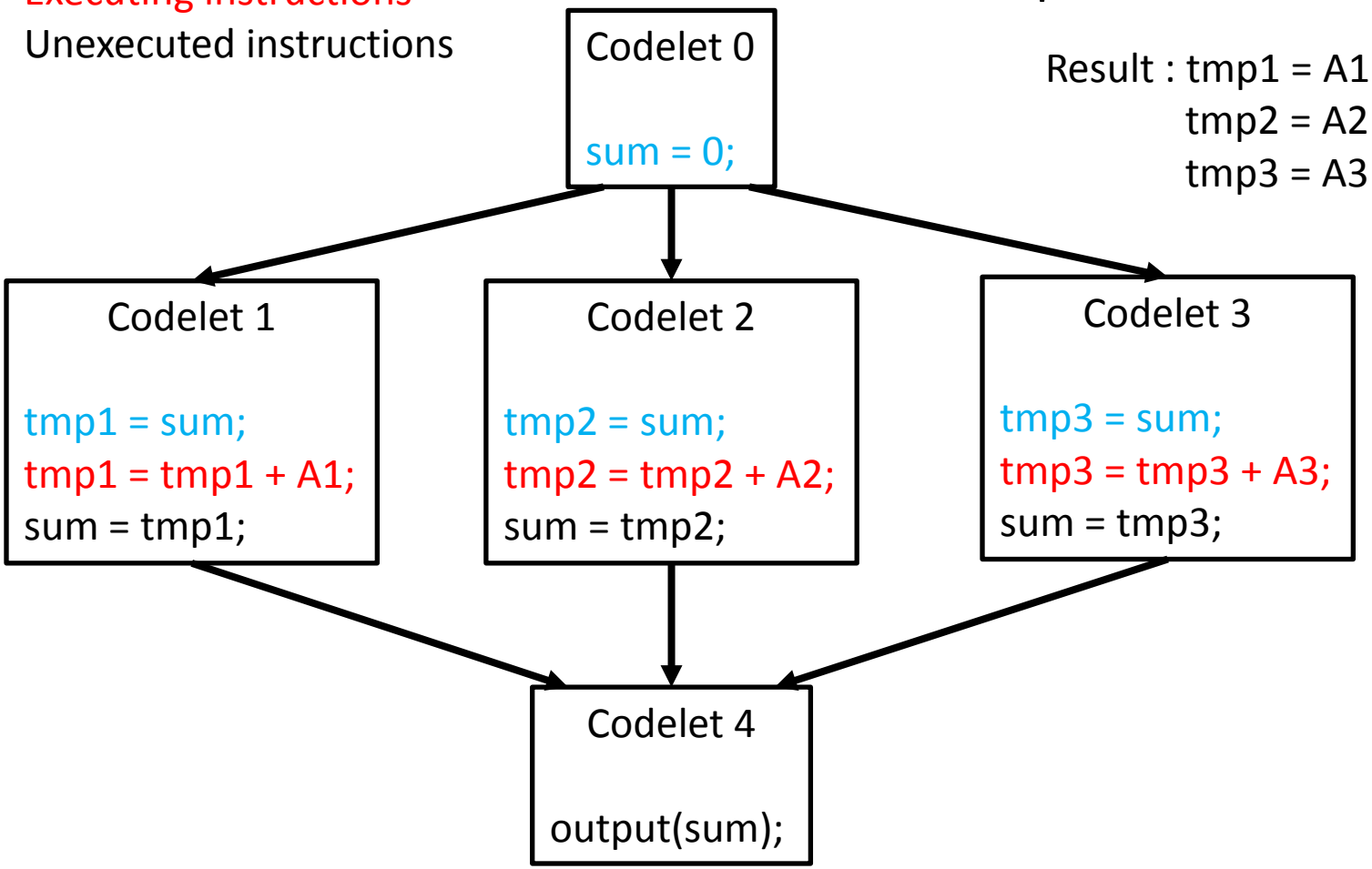


Example: Data Race in Computing Sum

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Result : tmp1 = A1
tmp2 = A2
tmp3 = A3



Example: Data Race in Computing Sum

Executed instructions
Executing instructions
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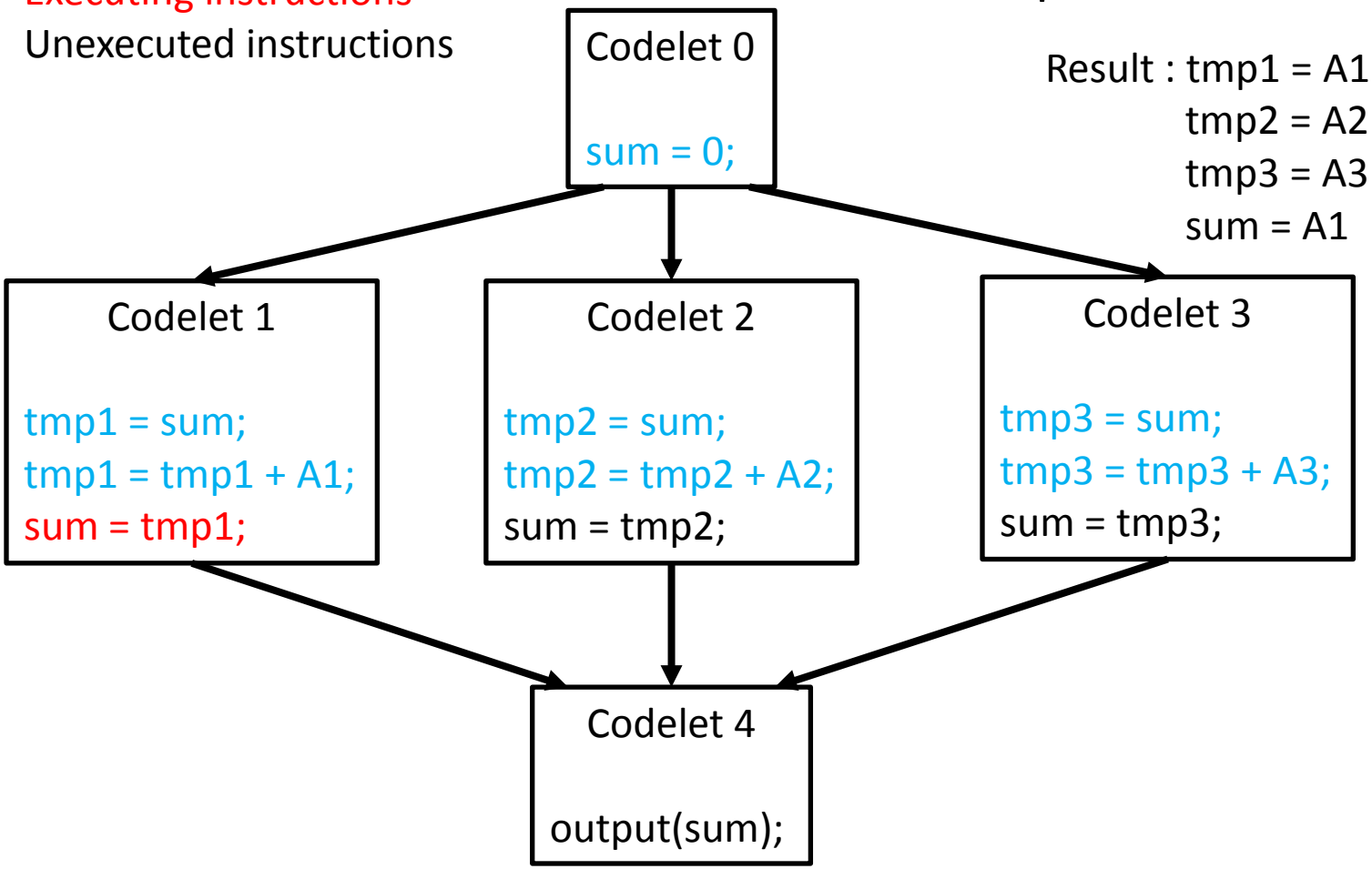
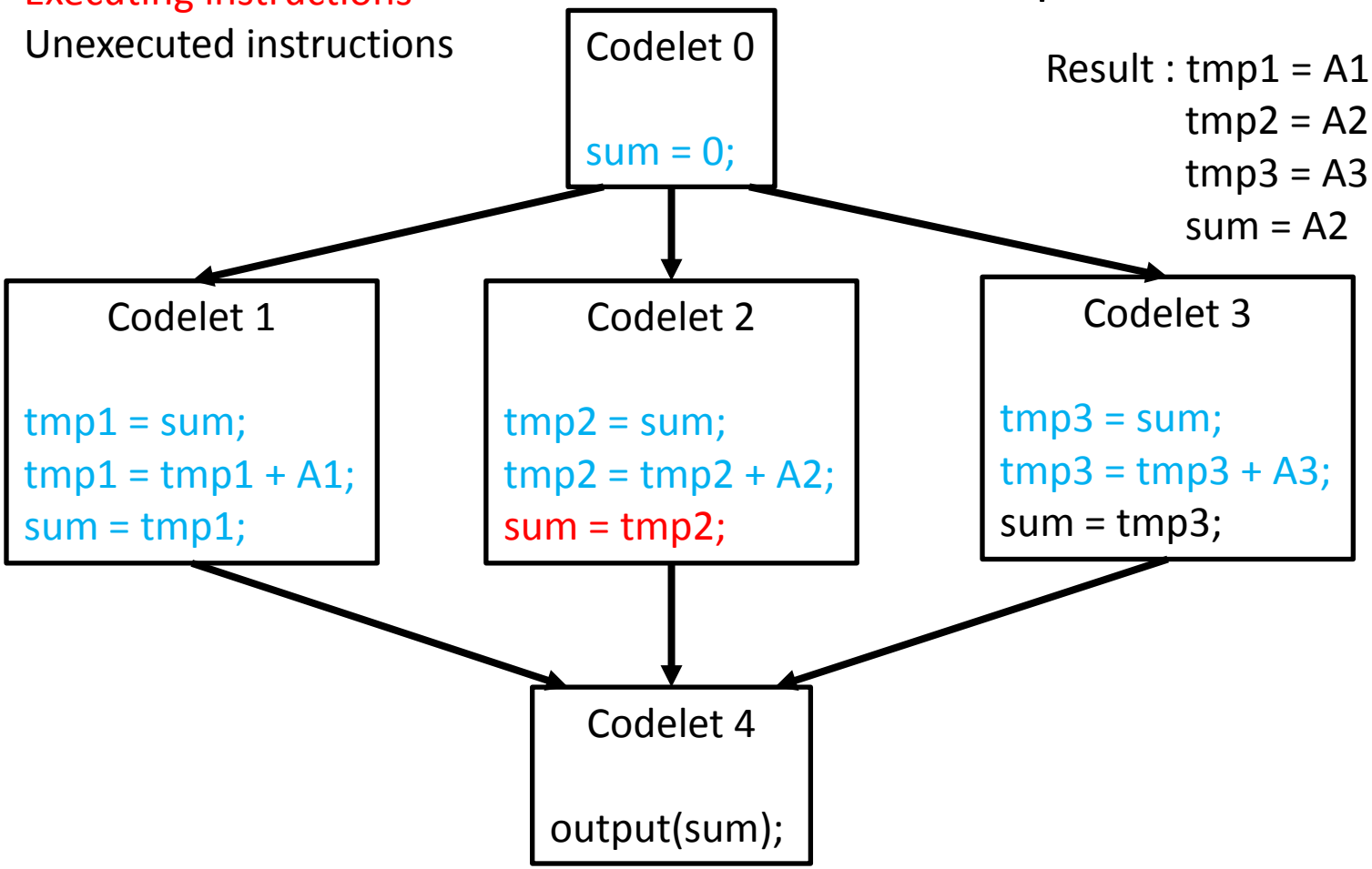
Compute sum = A1 + A2 + A3



Example: Data Race in Computing Sum

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

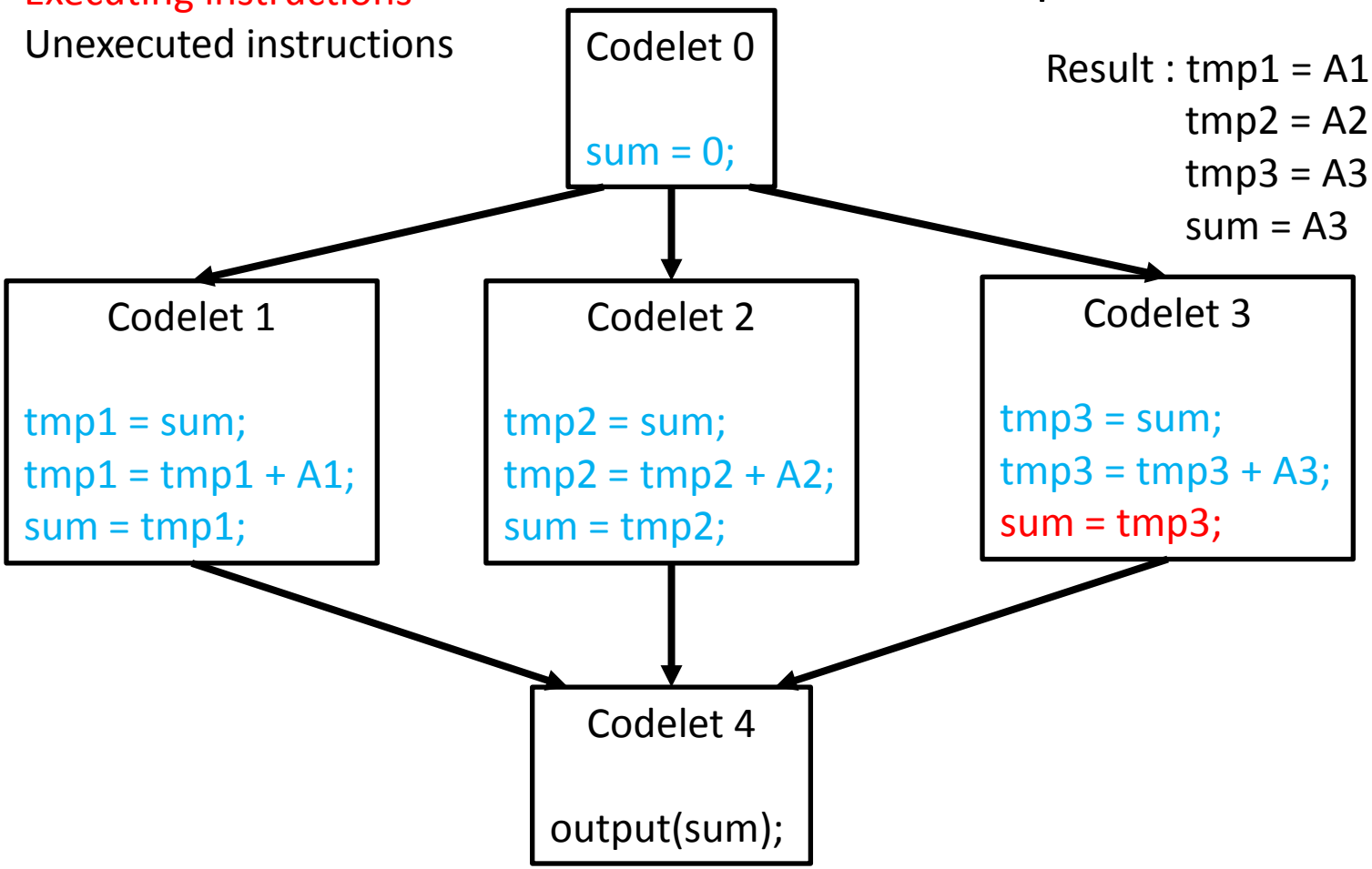


Example: Data Race in Computing Sum

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Result : tmp1 = A1
tmp2 = A2
tmp3 = A3
sum = A3

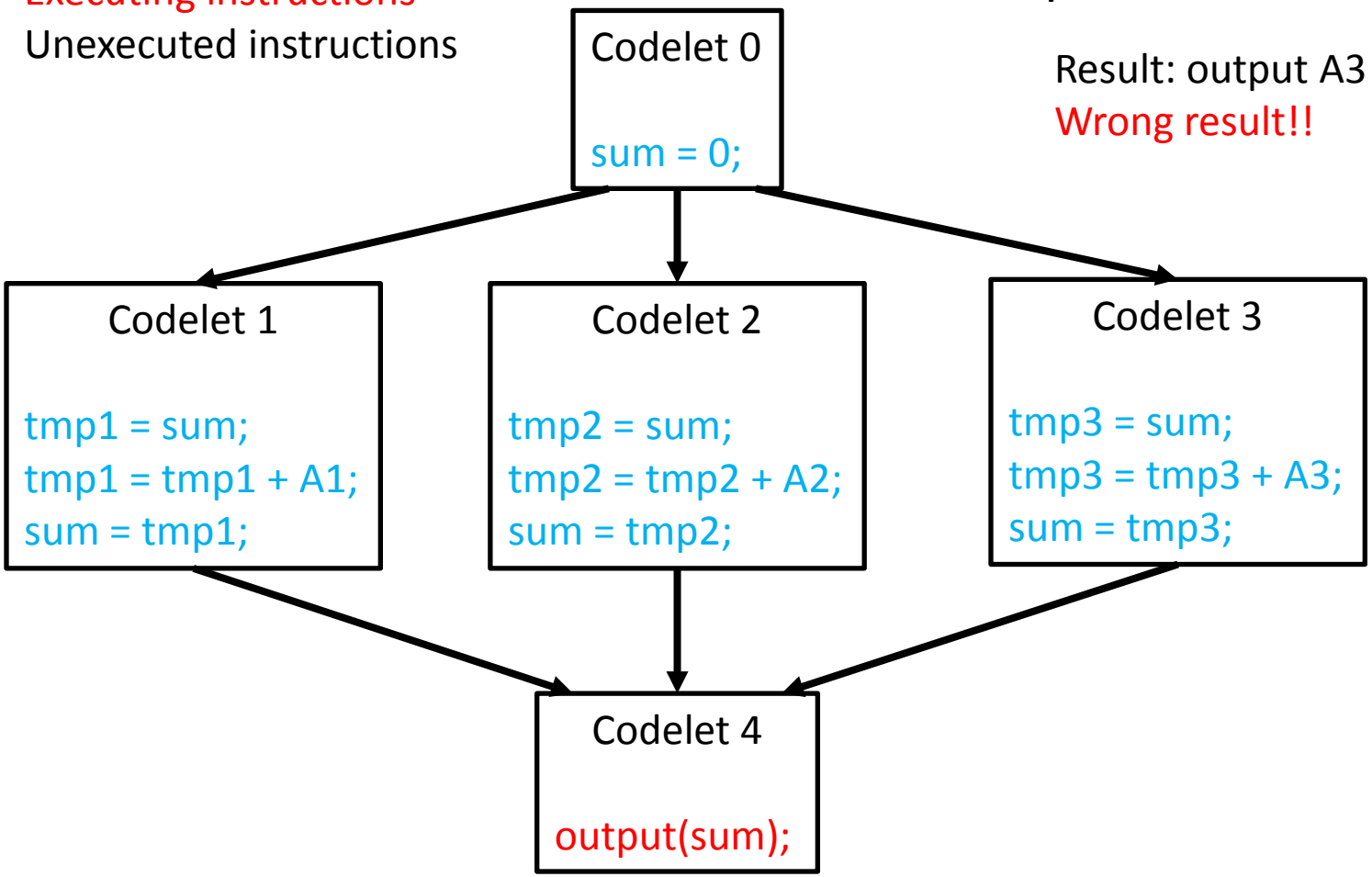


Example: Data Race in Computing Sum

Executed instructions
Executing instructions
Unexecuted instructions

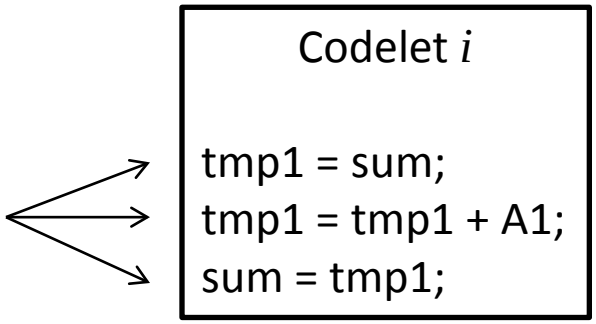
Compute sum = A1 + A2 + A3

Result: output A3
Wrong result!!



Example: Data Race in Computing Sum – Solution

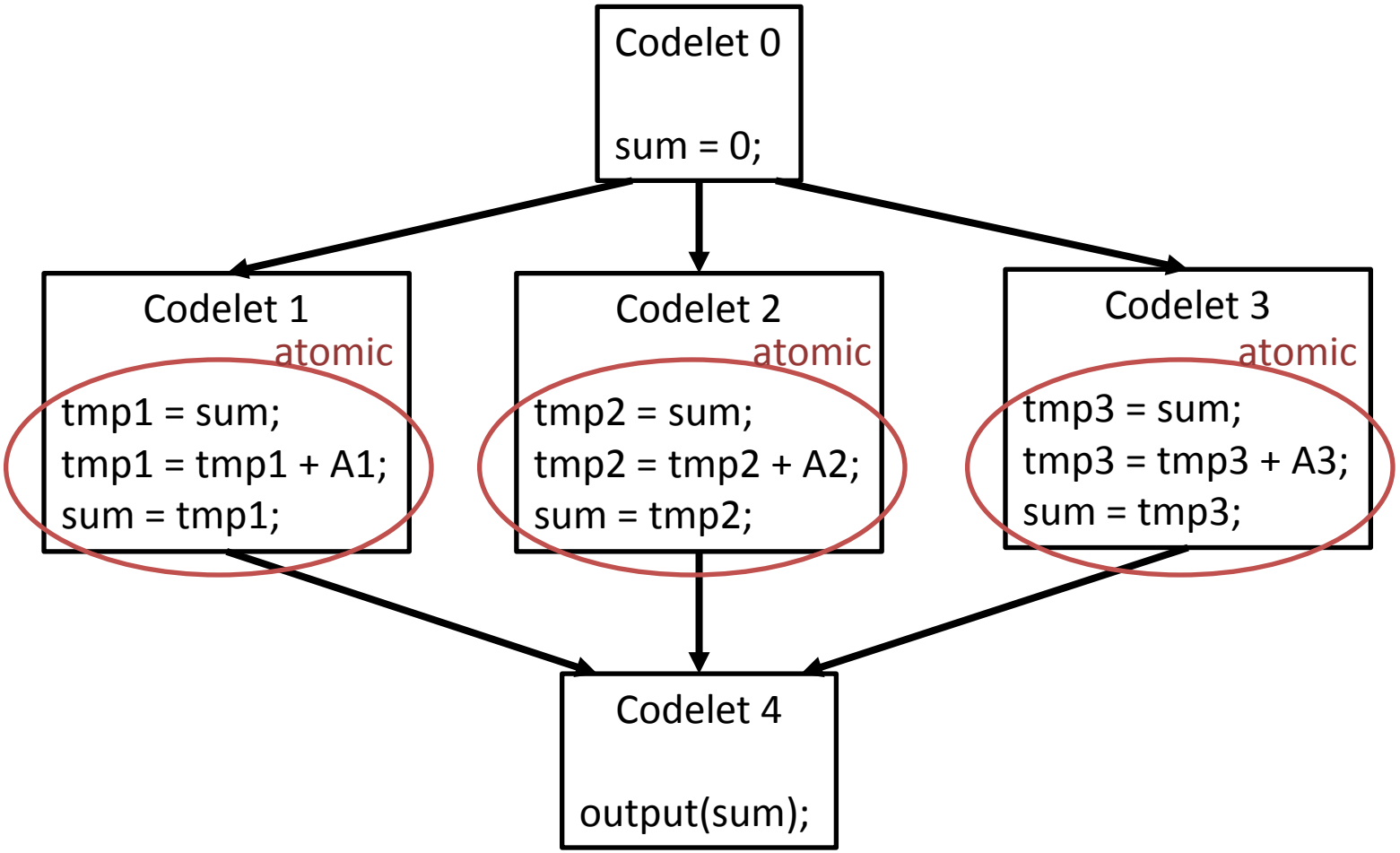
The three instructions must be executed **atomically**.



The three instructions must be executed as if one instruction. When the codelet computes sum, the other codelets must not change the value of sum.

Example: Data Race in Computing Sum – Solution

Compute sum = A1 + A2 + A3

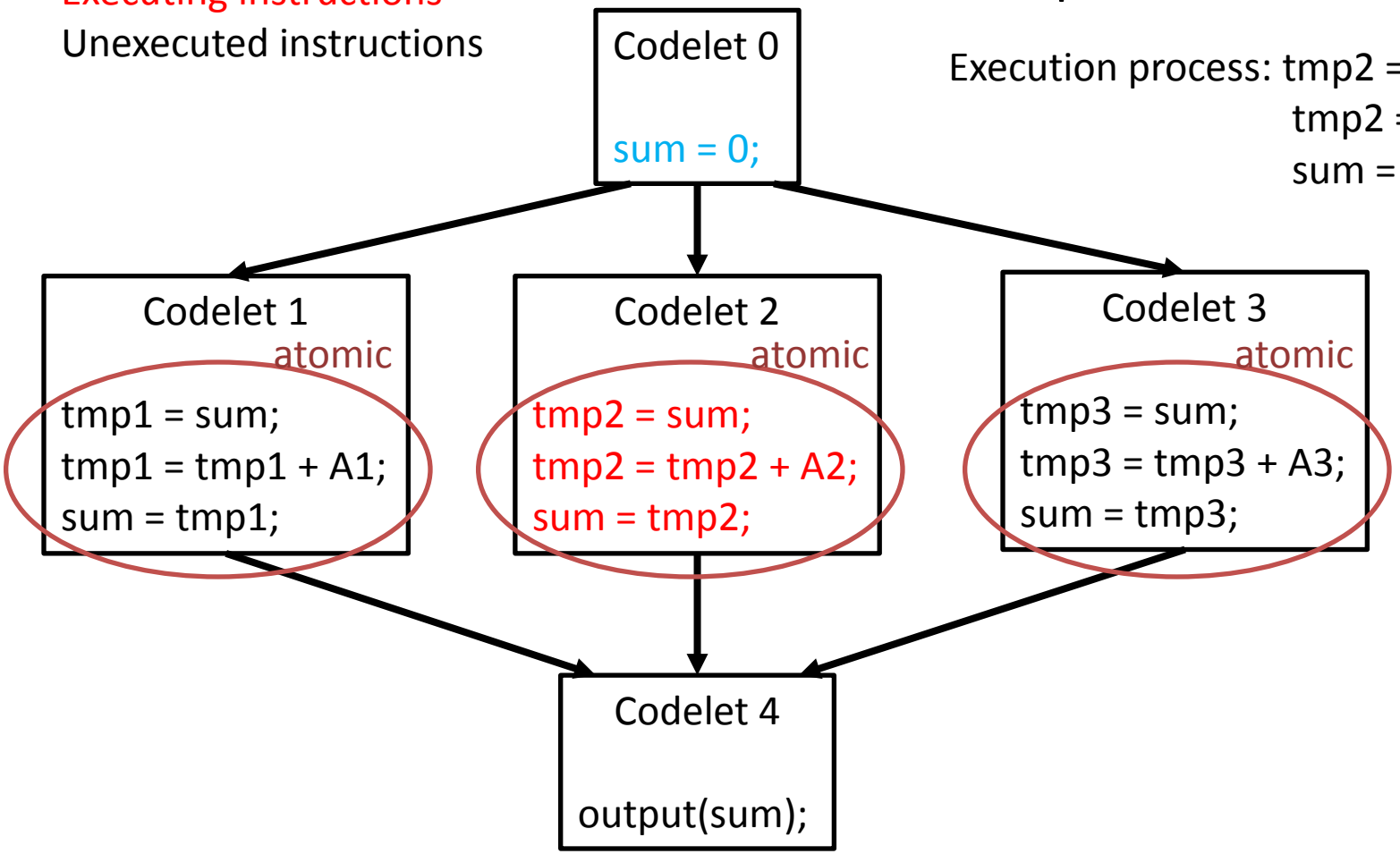


Example: Data Race in Computing Sum – Solution

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Execution process: tmp2 = 0
tmp2 = A2
sum = A2

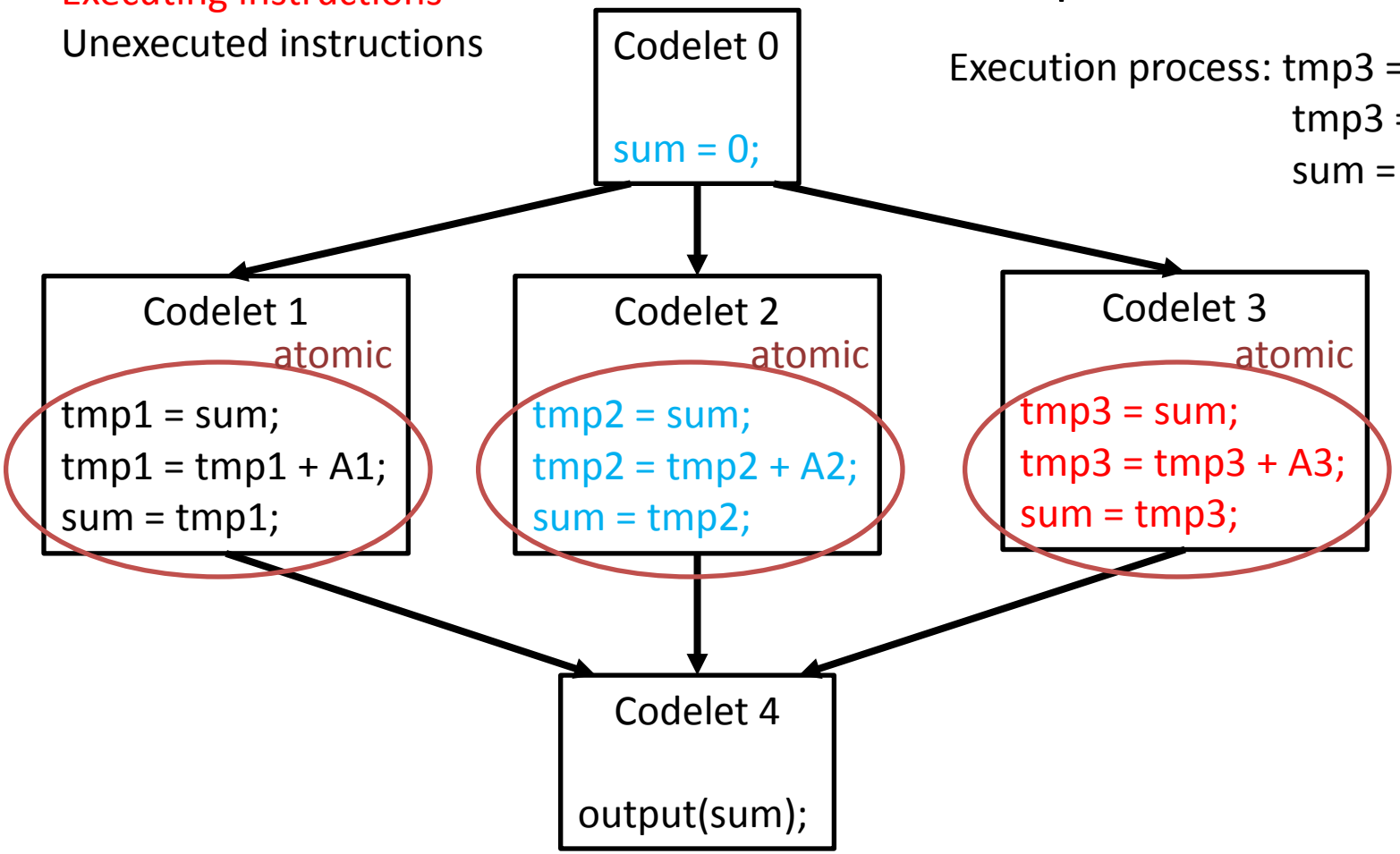


Example: Data Race in Computing Sum – Solution

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Execution process: tmp3 = A2
tmp3 = A2+A3
sum = A2+A3

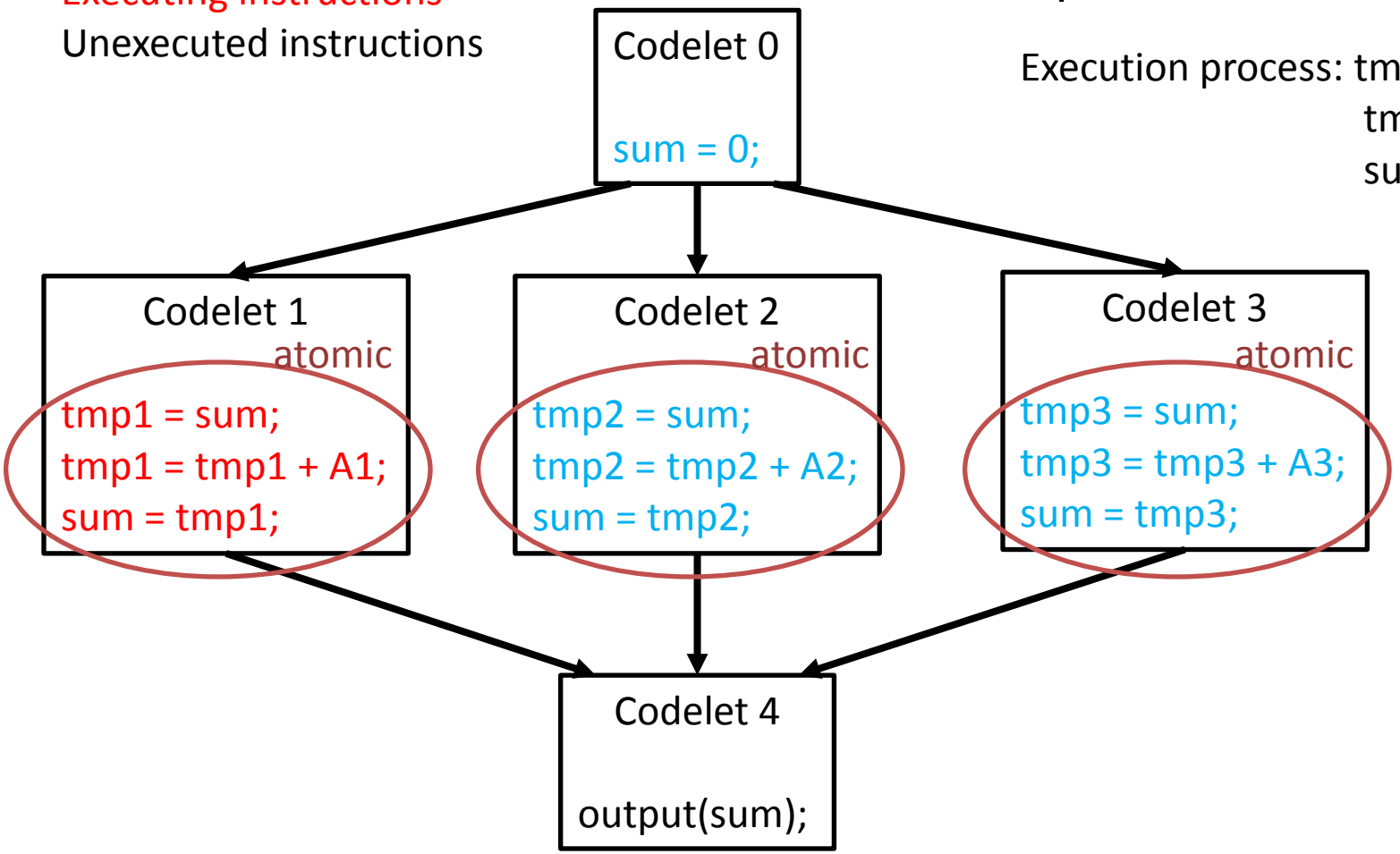


Example: Data Race in Computing Sum – Solution

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Execution process: tmp1 = A2+A3
tmp1 = A1+A2+A3
sum = A1+A2+A3

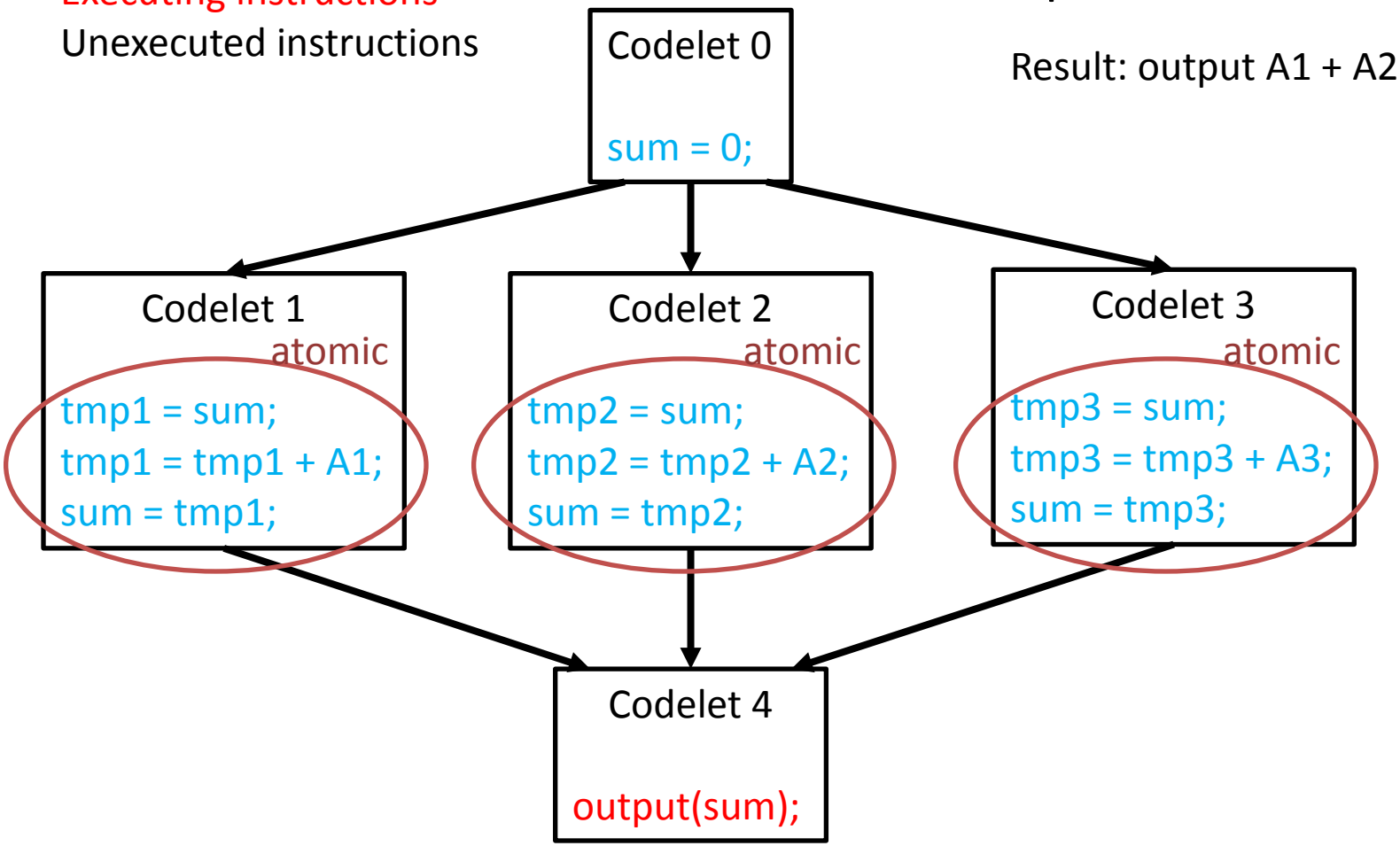


Example: Data Race in Computing Sum – Solution

Executed instructions
Executing instructions
Unexecuted instructions

Compute sum = A1 + A2 + A3

Result: output A1 + A2 + A3



Atomic Operations in SWARM

- swarm_atomic_getAndAdd(var, val)
  - Atomically do the following work
    - ret = var
    - var = var + val
    - return ret
- swarm_atomic_cmpAndSet(var, val, newVal)
  - Atomically do the following work
    - If var == val, then {var = newVal; return true;}
    - Otherwise, return false

More Information About Atomic Operations – Read SWARM Document

- General information about atomic operations: share/doc/swarm/programmers-guide/sec_coding_atomics.htm and share/doc/swarm/programmers-guide/sec_coding_atomics_naming.htm
- Information about atomic get and add: share/doc/swarm/programmers-guide/sec_coding_atomics_rmw.htm
- Information about atomic compare and set: share/doc/swarm/programmers-guide/sec_coding_atomics_access.htm

Outline

- Introduction to SWARM
- Programming in SWARM
- Atomic Operations in SWARM
- **Parallel For Loop in SWARM**

Parallel For Loop in SWARM (1)

Problem formulation: Suppose we have the following for loop where loop iterations can be executed in arbitrary order. How can we parallel the for loop in SWARM?

```
for (i = 0; i < N; i++)
        foo(i);
```

Parallel For Loop in SWARM (2)

Problem formulation: Suppose we have the following for loop where loop iterations can be executed in arbitrary order. How can we parallel the for loop in SWARM?

```
for (i = 0; i < N; i++)
        foo(i);
```

Methodology 1: Spawn N codelets. Each codelet does one foo(i). Not recommended due to heavy overhead.

Parallel For Loop in SWARM (3)

Problem formulation: Suppose we have the following for loop where loop iterations can be executed in arbitrary order. How can we parallel the for loop in SWARM?

```
for (i = 0; i < N; i++)
        foo(i);
```

Methodology 1: Spawn N codelets. Each codelet does one foo(i). Not recommended due to heavy overhead.

Methodology 2: Spawn k codelets. Each codelet does N/k foo(i)s. Good for balanced workload. Not good for unbalanced workload.

Parallel For Loop in SWARM (4)

Problem formulation: Suppose we have the following for loop where loop iterations can be executed in arbitrary order. How can we parallel the for loop in SWARM?

```
for (i = 0; i < N; i++)
        foo(i);
```

Methodology 1: Spawn N codelets. Each codelet does one foo(i). Not recommended due to heavy overhead.

Methodology 2: Spawn k codelets. Each codelet does N/k foo(i)s. Good for balanced workload. Not good for unbalanced workload.

Methodology 3: Spawn k codelets. Each codelet dynamically execute foo(i)s. Good for unbalanced workload.

Parallel For Loop in SWARM (5)

```
static void startup(void *unused)
{
   unsigned i;
   (void)unused;
   // COUNT is total number of threads
   swarm_dependency_init(&dep, COUNT, done, NULL);
   for(i=0; i<COUNT; i++)
      swarm_scheduleGeneral(dotproduct, (void *)(size_t)i);
}

static void dotproduct(void *_tid)
{
   const unsigned tid = (size_t)_tid;
   unsigned i;
   // LEN is length of the array
   sum[tid] = 0;
   for (i = tid * LEN / COUNT; i < (tid + 1) * LEN / COUNT; i++)
      sum[tid] += v1[i] * v2[i];

   swarm_satisfy(&dep, 1);
}
```

```
static void done(void *unused)
{
   unsigned i;
   (void)unused;
   int result;

   result = 0;
   for (i = 0; i < COUNT; i++)
     result += sum[i];

   printf("Result is : %d\n", result);
   swarm_shutdownRuntime(NULL);
}
```

Example of using methodology 2 for vector dot product

Parallel For Loop in SWARM (6)

```
for (i = 0; i < N; i++)
        foo(i);
```

Methodology 3: Spawn k codelets. Each codelet dynamically execute foo(i)s. How?

Codelet

(1) Get first index of unexecuted loop iteration and stored in i
(2) Increase the index by CHUNK_SIZE
(3) Executes foo(i), foo(i+1), …, foo(i+CHUNK_SIZE-1)

Hints: Steps (1) and (2) must be done atomically.
Once i >= N, the codelet is completed
Correctly handle the case that i + CHUNK_SIZE >= N

Parallel For Loop in SWARM (7)

Set and Get maximum number of threads

Set maximum number of threads

```
swarm_Runtime_params_t p;
swarm_Runtime_params_init(&p);
if (M_NUM_THREADS > 0) p.maxThreadCount = m_numthreads;

if(!swarm_enterRuntime(&p, startup, _ctxt)) { //startup : entry codelet
//_ctxt: parameter passing to startup
        fprintf(stderr, "%s: unable to start SWARM runtime\n", *argv);
        return 64;
}
```

Parallel For Loop in SWARM (8)

Set and Get maximum number of threads

Get maximum number of threads

```
unsigned GetSwarmThreadCount() {//return maximum number of threads
    const swarm_ThreadLocale_t *top = swarm_topmostLocale;
    size_t k;
    if(!top) return 1;
    k = swarm_Locale_getChildren(
        swarm_ThreadLocale_to_Locale(top), NULL, 0);
    return k+!k;
}
```