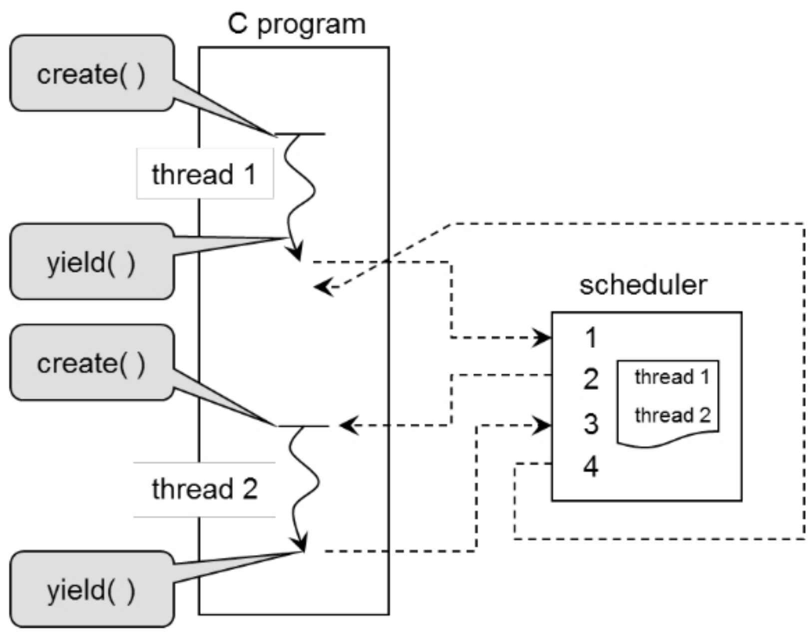
Mapping DFGs to Single Processors: Multi-Thread Dynamic Schedule

In multi-threaded programming, each *actor* (implemented as a function) lives in a separate thread

The threads are time-interleaved by a scheduler in single processor environments

Systems in which threads **voluntarily** relinquish control back to the scheduler is referred to as ***cooperative*** multithreading



Such a system can be implemented using two functions *create()* and *yield()* as shown

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The scheduler can apply different strategies to schedule threads, with the simplest one shown above as a *round-robin* schedule

Quickthreads is a **cooperative multithreading** library

The quickthreads API (Application Programmers Interface) consists of 4 functions

- *spt_init()*: initializes the threading system
- *spt_create(stp_userf_t *F, void *G)* creates a thread that will start execution with user function *F*, and will be passed a single argument *G*
- *stp_yield()* releases control over the thread to the scheduler
- *stp_abort()* terminates a thread (prevents it from being scheduled)

Here's an example

```
#include "../qt/stp.h"
#include <stdio.h>
```

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```
void hello(void *null)
    {
    int n = 3;
    while (n-- > 0)
        {
        printf("hello\n");
        stp_yield();
        }
    }

void world(void *null)
    {
    int n = 5;
    while (n-- > 0)
        {
        printf("world\n");
        stp_yield();
        } }
```

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```
int main(int argc, char **argv)
    {
    stp_init();
    stp_create(hello, 0);
    stp_create(world, 0);
    stp_start();
    return 0;
    }
```

To compile and execute:

```
gcc -c ex1.c -o ex1 ../qt/libstp.a ../qt/libqt.a
./ex1
hello
world
hello
world
hello
world\nworld\nworld
```

Mapping DFGs to Single Processors: Multi-Thread Dynamic Schedule

A multi-threaded version of the SDF scheduler, using the *fft2 actor*

```
void fft2(actorio_t *g) {
    int a, b;
    while (1)
        {
        while (fifo_size(g->in[0]) >= 2)
            {
            a = get_fifo(g->in[0]);
            b = get_fifo(g->in[0]);
            put_fifo(g->out[0], a+b);
            put_fifo(g->out[0], a-b);
            }
        stp_yield();
        }
```

Mapping DFGs to Single Processors: Multi-Thread Dynamic Schedule

```
void main()
    {
    fifo_t q1, q2, q3, q4;
    actorio_t fft2_io = {{&q2}, {&q3}};
    ...
    stp_create(fft2, &fft2_io); // create thread
    ...
    stp_start();          // start system scheduler
    }
```

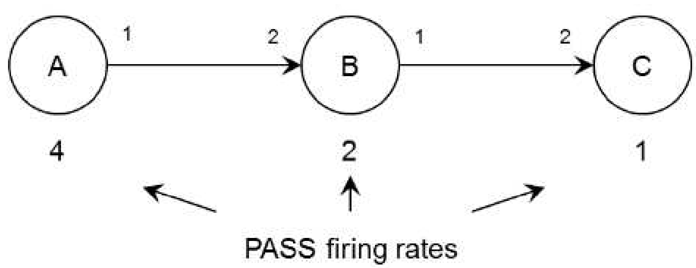
Note, as before, the *actor* code must enable convergence to the PASS *firing rate* (through while loops) in order to avoid *queue* overflow

Mapping DFGs to Single Processors: Static Schedule

From the PASS analysis of an SDF graph, we know at least one solution for a feasible sequential schedule

This solution can be used to optimize the implementation in several ways

- We can remove the *firing rules* since we know the exact sequential schedule
  This yields only a small performance benefit
- We can also determine an optimal interleaving of the *actors* to minimize the storage requirements for the *queues*
- Finally, we can create a fully **inlined** version of the SDF graph which eliminates the *queues* altogether




```
while(1) {
  // call A four times
  A(); A(); A(); A();

  // call B two times
  B(); B();

  // call C one time
  C();
}
```

Here, the relative *firing rates* of A, B, and C must be 4, 2, and 1 to yield a PASS

Mapping DFGs to Single Processors: Static Schedule

Given the interleaving schedule on the right, *queue* AB will need to store at most 4 *tokens* and *queue* BC at most 2 *tokens* in steady-state

However, the interleaving schedule (A,A,B,A,A,B,C) is better because the maximum # of tokens on any *queue* is now 2

Therefore, the schedule determined using PASS is **not** necessarily the optimal (in fact, finding the best schedule is an optimization problem)

As noted, implementing a truly static schedule means we do NOT need to check *firing rules* since the required tokens are guaranteed to be present

Consider optimizing the four-point FFT with a **single-thread** SDF system and a **static schedule**

The 3 *actors*, *reorder*, *fft2* and *fft4mag*, have firing rates 1, 2 and 1, which yields a static, cyclic schedule [*reorder*, *fft2*, *fft2*, *fft4mag*]

Software Implementation: Sequential Targets with Static Schedule

There are two simple **optimizations** that can be applied here

- The *firing schedule* is **static** and **fixed**, and therefore the access order of *queues* is also fixed

  This allows the queues to be *optimized out* and replaced with **fixed variables**

The *queue* access can be replaced as shown in the comments

```
loop {
    ...
    q1.put(value1); // replace with r1 = value1;
    q1.put(value2); // replace with r2 = value2;
    ...
    .. = q1.get(); // replace with .. = r1;
    .. = q1.get(); // replace with .. = r2;
    }
```

Software Implementation: Sequential Targets with Static Schedule

- A second optimization involves **inline**'ing the *actor* code in the main program

  In combination with the above optimization, this *eliminates* the *firing rules* and reduces the entire dataflow graph to a **single** function

```
void dftsystem(int in0, in1, in2, in3,
    *out0, *out1, *out2, *out3) {
    int reorder_out0, reorder_out1;
    int reorder_out2, reorder_out3;
    int fft2_0_out0, fft2_0_out1;
    int fft2_0_out2, fft2_0_out3;
    int fft2_1_out0, fft2_1_out1;
    int fft2_1_out2, fft2_1_out3;
    int fft4mag_0_out0, fft4mag_0_out1;
    int fft4mag_0_out2, fft4mag_0_out3;

// Reorder operation
    reorder_out0 = in0; reorder_out1 = in2;
    reorder_out2 = in1; reorder_out3 = in3;
```

Software Implementation: Sequential Targets with Static Schedule

```
// Two fft2 implementations
fft2_0_out0 = reorder_out0 + reorder_out1;
fft2_0_out1 = reorder_out0 - reorder_out1;
fft2_1_out0 = reorder_out2 + reorder_out3;
fft2_1_out1 = reorder_out2 - reorder_out3;

// fft4 implementation
fft4mag_out0 = (fft2_0_out0 + fft2_1_out0) *
               (fft2_0_out0 + fft2_1_out0);
fft4mag_out1 = (fft2_0_out1 * fft2_0_out1) -
               (fft2_1_out1 * fft2_1_out1);
fft4mag_out2 = (fft2_0_out0 - fft2_1_out0) *
               (fft2_0_out0 - fft2_1_out0);
fft4mag_out3 = (fft2_0_out1 * fft2_0_out1) -
               (fft2_1_out1 * fft2_1_out1);
```

Software Implementation: Sequential Targets with Static Schedule

These optimizations reduce the runtime of the program significantly

For example, we have eliminated testing of the *firing rules* and calls to the *queue* and *actor* functions

This is possible here because a *valid PASS* could be determined from the DFG, as well as *fixed schedule* to implement the PASS

Note that we have traded some of the **runtime flexibility** for **improved efficiency**