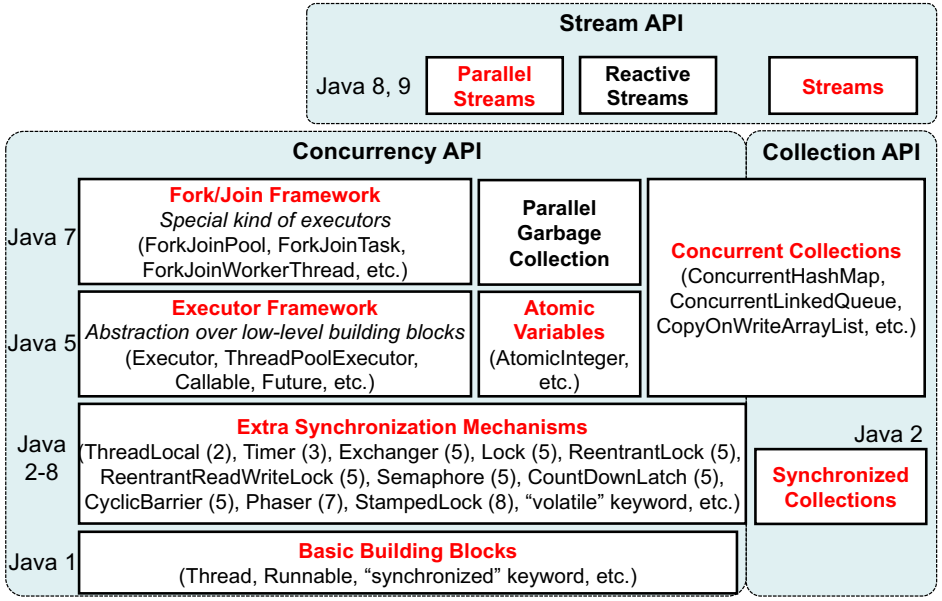
Executor Framework

Concurrency API in Java



Executor Framework

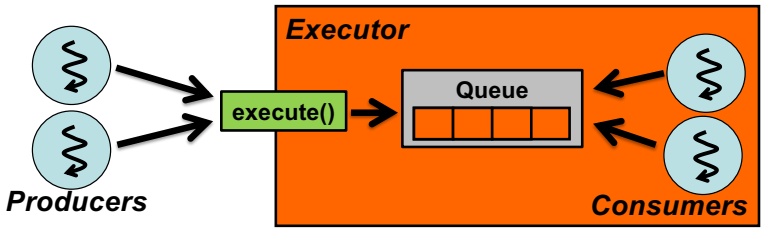
- An abstraction layer atop low-level concurrency primitives
  - Focuses on task execution on threads
  - Decouples task execution (on threads) from task submission (to threads) to make task execution configurable.
  - Introduced in Java 5 (2004)
    - Enhanced further in subsequent versions
  - Implemented in `java.util.concurrent`.

Tasks, Threads and Executor

- Tasks
  - Logical units of work
    - e.g., prime number generation, access counting for files, banking (deposit/withdrawal/wire transfer of money), file caching, file crawling, file indexing, etc.
- Threads
  - Mechanism to run tasks *concurrently*.
- Executor
  - Is the primary abstraction for task execution
    - `Thread` is NOT anymore.

Executor

- `public interface Executor{ void execute(Runnable task); }`
- `Runnable`'s `run()` implements a task.
- Producers: submit tasks
- Consumers: execute tasks
- Makes task execution configurable.

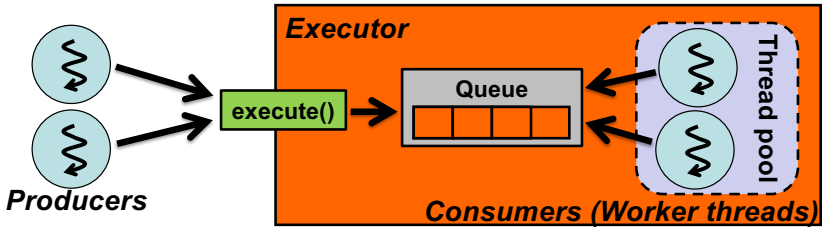


Task Execution Policies

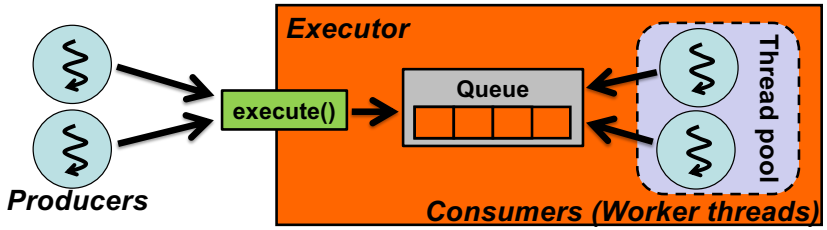
- The Executor framework allows you to specify and customize the *execution policy* for tasks.
  - "What, where, when and how" of task execution.
    - In which thread will tasks be executed?
    - In what order should tasks be executed (FIFO, LIFO, priority-based ordering)?
    - How many tasks may run concurrently.
    - How many tasks may be queued pending execution?
    - If a task has to be rejected because an application is overloaded, which task should be selected as the victim? How should the application be notified?
    - What actions should be taken before or after executing a task?

Thread Pool

- A key component for task execution.
- A set of pre-created "worker" threads that will be used for future task execution
- Each worker thread
  - Gets and executes a task if it is available in the queue.
  - Goes to the Waiting state, if no tasks are available in the queue, until a producer submits the next task.



- Benefits of using a thread pool
  - Can eliminate runtime overhead to create threads
  - Can bound the maximum number of threads (i.e., the max amount of resource utilization)
    - Running too many threads (i.e., consuming too much resources) will result in a crash of operating system.



Executors

- A utility class for `Executor` objects
  - Defines static factory methods to create an executor with a particular thread pool.

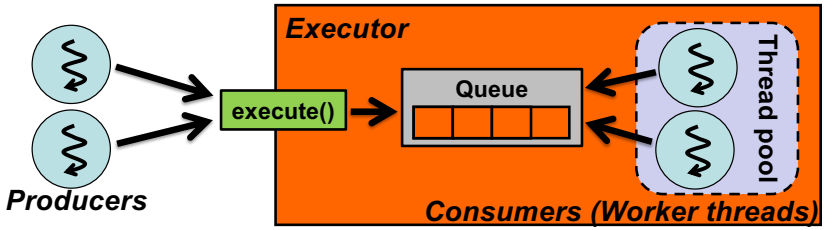
- `static ExecutorService newFixedThreadPool(int n)`
  - Fixed-size thread pool

```
ExecutorService executor = Executors.newFixedThreadPool(2);
executor.execute( new PrimeNumberGenerator(1L, 500000L) );
executor.execute( new PrimeNumberGenerator(500001L, 1000000L) );
```

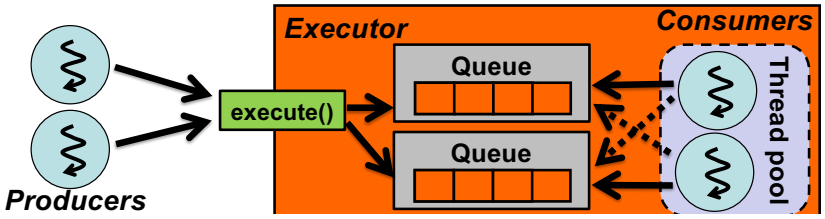
```
Thread t1, t2;
t1 = new Thread( new PrimeNumberGenerator(1L, 500000L) );
t2 = new Thread( new PrimeNumberGenerator(500001L, 1000000L) );
t1.start();
t2.start();
```


- Static factory methods
  - `static ExecutorService newFixedThreadPool(int n)`
    - Fixed-size thread pool.
  - `static ScheduledExecutorService newScheduledThreadPool(int n)`
    - Fixed-size thread pool that supports delayed and periodic task execution.
  - `static ExecutorService newSingleThreadExecutor()`
    - A pool that operates only one thread.
  - `static ScheduledExecutorService newSingleThreadScheduledExecutor()`
    - A single-threaded pool that supports delayed and periodic task execution.

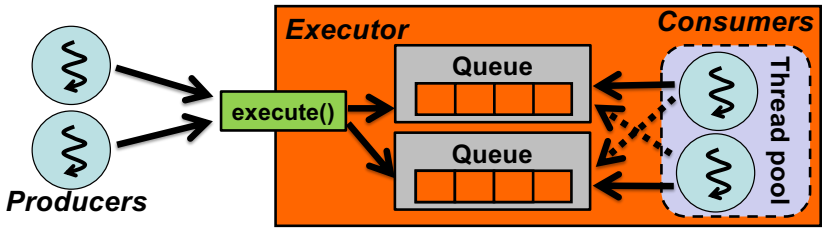
- `static ExecutorService newCachedThreadPool()`
  - Variable-size (not fixed-size) thread pool.
    - Uses previously created "idle" threads if they are available.
    - Creates a new thread if no idle threads are available.
    - Idle threads are terminated and removed from the pool after they are not used for 60 seconds.
  - Pros:
    - Can minimize the number of tasks in the queue.
    - Can minimize the number of threads (resource consumption)
  - Cons: No cap for the number of threads in the pool.
  - Useful to handle a number of *short-lived* (lightweight) tasks



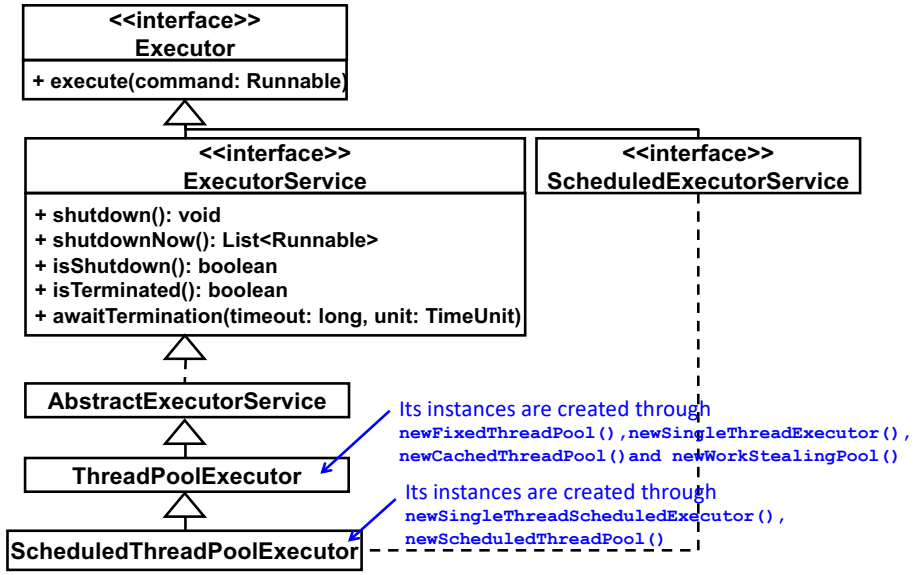
- `static ExecutorService newWorkStealingPool(int parallelism)`
  - Variable-size thread pool with a cap for the # of threads.
    - `Parallelism` specifies the cap for the # of threads.
  - Each worker thread
    - Has its own "primary" queue and gets the next task from the queue.
    - "Steals" a task from another queue if no tasks are available in its primary queue.
    - Dies after being idle for some time.
  - Pros:
    - Each queue requires less thread synchronization.
    - Can minimize the # of tasks in a queue and bound the # of worker threads.
  - Cons: No guarantee about the order task execution



- `static ExecutorService newWorkStealingPool()`
  - Obtains the number of available CPU cores by calling `availableProcessors()` and invokes the previous version of `newWorkStealingPool()`

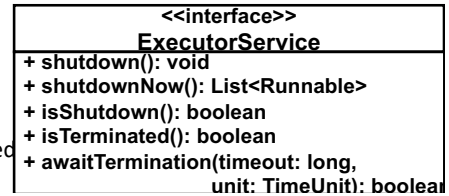


ExecutorService

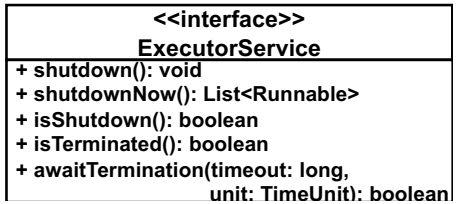


Termination of Executor

- Methods to terminate an executor
  - **`shutdown()`**
    - Rejects new tasks to get in
      - Throws a **`RejectedExecutionException`**
    - Allows previously submitted tasks to complete
      - Tasks being executed and tasks in the queue
  - **`shutdownNow()`**
    - Rejects new tasks to get in
    - Removes all tasks from the queue and returns them
    - Tries to stop the tasks that are being executed.
      - Call **`interrupt()`** on each worker thread
    - A task can be stopped if it checks `Thread.interrupted()` or catches `InterruptedException` to exit `run()`.
      - Otherwise, it may not be stopped



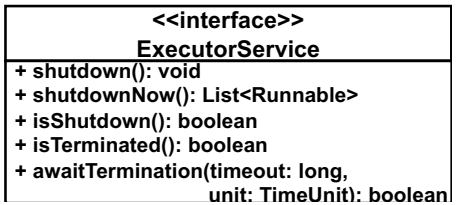
- 3 states of an executor
  - Running
  - Shutting down
    - Once `shutdown()` or `shutdownNow()` is called.
    - `isShutdown()` returns true.
  - Terminated
    - Once all tasks have been completed or stopped.
    - `isTerminated()` returns true.



- Use `awaitTermination()` if you wait for an executor to be terminated.
  - It blocks until the executor is terminated or the timeout occurs.
  - It returns true if the executor is terminated or false otherwise.

```
executor.shutdown();
executor.awaitTermination(Long.MAX_VALUE, TimeUnit.SECONDS);
doSomething();
```

```
executor.shutdown();
if(!executor.awaitTermination(60, TimeUnit.SECONDS)){
    shutdownNow();
    if(!executor.awaitTermination(60, TimeUnit.SECONDS)){
        doErrorHandling();
    }
}
```



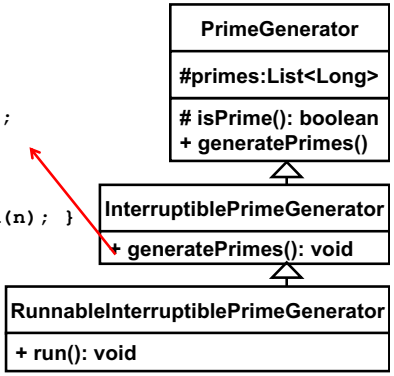
Sample Code: RunnableInterruptiblePrimeGenExecutorTest.java

```
RunnableInterruptiblePrimeGenerator r1, r2;
r1 = new RunnableInterruptiblePrimeGenerator(1L, 500000L);
r2 = new RunnableInterruptiblePrimeGenerator(500001L, 1000000L);

ExecutorService executor = Executors.newFixedThreadPool(2);

executor.execute(r1);
executor.execute(r2);

executor.shutdown();

//executor.shutdownNow();
    // Calls interrupt() on each prime gen thread. An
    // interruption is caught by Thread.interrupted() in
    // RunnableInterruptiblePrimeGenerator's run().

executor.awaitTermination(...);

r1.getPrimes().forEach(...);
r2.getPrimes().forEach(...);
```


RunnableInterruptiblePrimeGenerator

- Detect an interruption from another thread to stop generating prime numbers.

```
for (long n = from; n <= to; n++){
    if(Thread.interrupted()){
        System.out.println("Stopped");
        this.primes.clear();
        break;
    }
    if( isPrime(n) ){ this.primes.add(n); }
}
```



- If you use shutdown(),
  - Two runnable tasks generate all primes.
    - gen1 generated 41538 prime numbers.
    - gen2 generated 36960 prime numbers.

- If you use shutdownNow(),
  - Two runnable tasks cancel prime generation
    - Stopped generating prime numbers due to a thread interruption.
    - Stopped generating prime numbers due to a thread interruption.
    - gen1 generated 0 prime numbers.
    - gen2 generated 0 prime numbers.