CS 478: Software Development for Mobile Platforms

Set 5: Multi-threading

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Useful definitions

- *Process*: A self-contained program running with its own data
  - Processes execute in parallel (concurrently) with other processes (sharing such resources as memory, CPU, external storage, etc.)
  - In general, data not shared among processes
    - ➢ On multicore chips found in smart phones, processes can run *simultaneously,* each on a different core
  - *Simultaneous* vs. *concurrent* execution
    - ➢ Simultaneous = physically concurrent (at the very same time)
    - ➢ Logical concurrency sometimes through time-sharing one CPU
  - **Android**: In general each app runs on its own process
    - ➢ By default, all components in an app run in the same process

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Useful definitions

- *Thread:* A different kind of concurrent unit than a process
  - Like a process, a thread has its own control flow, runs asynchronously with respect to other threads
    - ➢ Each thread has its own run-time stack, registers
  - Part of a process
    - ➢ A process can have multiple threads
  - However, a thread shares statically-allocated and dynamically-allocated objects with other threads in same process
  - Thread = A light-weight process?
  - **Android**: Each app given a thread called *main* or the *UI Thread*

See http://developer.android.com/guide/components/processes-and-threads.html

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Process hierarchy

Used to determine what process to kill when system is low on resources

1. *Foreground process*: Required for what the user does now, may host either:
   - Resumed activity
   - Service bound to resumed activity
   - Service running lifecycle callbacks (e.g., *onCreate()*)
   - Broadcast receiver running *onReceive()*

- Android will not destroy a foreground processes except under catastrophic lack of resources (CPU time, RAM, etc.)

See https://developer.android.com/guide/topics/processes/process-lifecycle.html

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Process hierarchy

2. *Visible process*: Does work the user can see or hear, may host either:
   – Activity in paused state
   – Service bound to paused activity
   – Service running in foreground (e.g., playing music)

• Fairly safe from automatic killing by OS even when resources are very scarce

See https://developer.android.com/guide/topics/processes/process-lifecycle.html

Process hierarchy

3. *Service process*: Process running a service in background (e.g., synchronizing with a server or downloading data)
   – Doing things user cares about but not affecting UX
   – Could be killed by OS
4. *Cached process*: Process running an activity that's not visible (stopped)
   – Least recently used processes are good targets for killing
   – Empty process: Process doing nothing (cached for future reuse?)

See https://developer.android.com/guide/topics/processes/process-lifecycle.html

The *Main Thread*

- Android app has its own process but can contain multiple threads
- Apps we saw thus far had just one thread
- *Main thread*: App's initial thread when app starts execution
- Also known as the *UI thread*
  - **Main thread is the only app thread allowed to modify the app's display**
  - Main thread has an event queue where requests are posted (e.g., to update UI widgets or execute callbacks)
  - When new components are created (e.g., starting a service, executing *onReceive*()) they still run in the main thread

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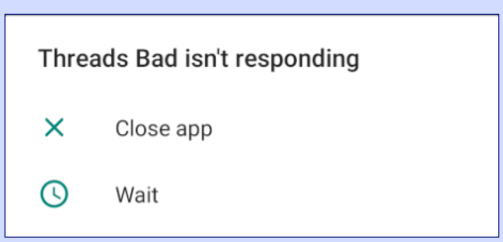
The *Main Thread* (cont'd)

- Be careful not to put too many computations in the UI thread
  - ➢ If the UI thread busy computing, it won't respond to new events
- Android checks periodically whether an app's UI is responsive or not
- If no response 5 seconds after user event, Android will display infamous *ANR* (*Application not Responding*) dialog to kill running application, possibly leading frustrated user to uninstall your app
  - ➢ You probably don't want that fate for your app…



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The *Main Thread* (cont'd)

- Conclusion: If you must run long computations, spawn a worker thread and run computations in worker thread...
  - **... But then change the UI in the UI thread**
  - E.g., database operations, page download or other network access should never be done in UI thread...

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The bottom line

- Two simple rules to live happily with Android threads:
  1. **Don't ever block the UI Thread (i.e., avoid ANR)**
  2. **Don't ever change the UI from another thread**
     - Only UI thread allowed to modify the UI
- Consequences:
  1. Use worker thread for long-running computations
  2. Let UI thread post computation results on device's display
- Two approaches to multi-threading Android apps
  – Java threading capabilities, e.g., *Thread* class and *Runnable* interface
  – Added-on Android threading functionality (e.g., *AsyncTasks* and *Handlers*)

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Managing the threads

- Somewhat tricky
  - Must do background work in worker thread but update UI in main thread
  - The UI thread is not thread-safe!
    - Different threads will be reading and writing shared data structures
    - Access to shared structures by different threads must be synchronized to avoid simultaneous access and possibly inconsistent changes

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Concurrency in Java

- Java language supported concurrency from the outset
- Two main units for defining threads
  - Class *Thread*—Instances of this class can be run in parallel with each other and with the main thread
  - Interface *Runnable*—Define objects that can be passed to thread instances for execution in parallel
- Both *Thread* and *Runnable* declare method *run()* which specifies code to be executed in a separate thread
- When program starts, user code is executed in a single (main) thread
- Programmer can spawn additional threads as program runs by creating and *start*ing additional *Thread* instances

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Java's concurrency model

- Multiple threads can be run concurrently (either through logical or physical concurrency, if enough cores are not available)
  - ➢ Logical concurrency: Multiple threads share time slices on the same core or CPU
  - ➢ Physical concurrency: Multiple threads run at the same time on different cores

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Java's concurrency model

Support for data structure sharing (i.e., objects and fields)

- Each Java object has a mutual exclusion lock associated with it
  - *Mutex* lock—Lock that can be held by a single thread at a time; other threads trying to grab the same lock will have to wait
  - Also known as **intrinsic lock** or **monitor lock**
- Objects accessed by multiple threads should be locked if one of the threads attempts to modify the object
- We'll see how…

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Creating and running Java threads

Simple steps for creating a Java thread:

1. Create class that either:
   – **extends** *Thread,* or
   – **implements** *Runnable*
2. Create a new thread instance either by
   – Creating **new** instance of your *Thread* subclass, or
   – Creating **new** instance of predefined *Thread* class while passing a *Runnable* instance to it
3. Start the *Thread* instance that you just created, e.g., by
   – Calling *aThread.start()* will cause *aThread* start executing its *run()* method

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Two recipes for creating threads

First recipe:

1. Define a subclass *MyThread* of *Thread*
   – *MyThread* will override method *run()* to do specific actions for that thread
   – Method *run()* in *Thread* does not nothing
   – E.g., **class** *MyThread* **extends** *Thread*
2. Create a **new** *MyThread()* instance
   – E.g., aThread := **new** *MyThread*() ;
3. Send message *start()* to the new instance of *MyThread*
   – E.g., aThread.*start()* ;
   – Now aThread will execute its *run()* method

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Two recipes for creating threads (cont'd)

Second recipe:

1. Define a class that implements *Runnable*
   - Since *Runnable* declares abstract method *run()*, your class must implement (give code for) *run()*
   - E.g., **class** *MyRunnable* **implements** *Runnable* …
2. Create a **new** *Thread*, initialize the thread by passing as argument an instance of your *Runnable* realization (e.g., *MyRunnable*)
   - E.g., Thread aThread = **new** Thread(**new** *MyRunnable()*) ;
3. Send message *start()* to the new thread instance
   - E.g., aThread.*start()* ;
   - Now aThread will execute its *run()* method

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Synchronized methods and blocks

- Basic mechanism for synchronizing access to shared structures
- **Synchronized block**: Locks object specified in *synchronized statement*
  - Two threads might be executing this code, but only one will be allowed to enter the *synchronized* block and access locked object
  - Syntax of synchronized statement:

```
synchronized(anObject){
    // statements to be executed by one thread at a time
}
```

  - Example:

```
synchronized(aPerson) {
  // read aPerson – aPerson accessed by multiple threads simultaneously
}
```

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Synchronized methods and blocks (cont'd)

- **Synchronized method**: Locks the method's receiver
  - Other threads trying to execute synchronized methods on the same receiver must wait
  - If method is static, the class of the method is locked (i.e., calls to other static methods in same class must wait)
  - Syntax:

{<*access-level*>} <*return-type*> **synchronized** <*method-name*>(<*parameter-list*>)

  - Example:

```
public void synchronized add(int i) {
  …
}
```


A simple threading example

- Design button in UI that downloads and displays web page
  - This is a long running operation, defer to another thread

```
…
theButtonThatAteChicago.setOnClickListener(new View.OnClickListener() {
  public void onClick(View v) {
     new Thread(new Runnable() {
         public void run() {
             Bitmap b = loadImageFromNetwork(
                          "http://example.com/image.png");
             mImageView.setImageBitmap(b);
         }
     }).start();
  }
```

Set a button listener.

Create new thread on user click.

Thread downloads image and sets content of image view.

Start executing thread's *run()* method.

This seems quite right!

But it's wrong!

Why??!?

Fixing the problem: *runOnUiThread()*

- Various ways to fix above issue
- Use method *runOnUiThread(Runnable)*
- Must provide *Runnable* object that will modify the UI
- Call to *runOnUiThread()* does not block caller
- Resulting code can be complicated
  – Ugo's note: Isn't this always the case with Android?

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Another solution: *AsyncTask*

- Special Android construct to make multithreading easier
- Goal: Delegate work away from UI Thread to a background thread
- *AsyncTask*: Background thread responsible for
  – Carrying out work
  – Reporting ongoing progress to UI thread
  – Returning final result to UI thread
- UI thread responsible for handling AsyncTask's results and updating display
  – Recall that only UI thread can update display
- Convenient alternative to *runOnUiThread(),* handlers and raw Java threads for short tasks (requiring 1-2 seconds at most)

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Division of labor

- UI thread
  - Creates instance of *AsyncTask* subclass, prepares for task execution, creates subclass instance, and calls *execute()* on instance
  - Displays progress reports while *AsyncTask* instance running
  - Updates display upon *AsyncTask* completion
- *AsyncTask*
  - Performs background work
  - Publishes progress status to UI Thread while running in background
  - Returns results of background work to UI thread
  - A realization of pattern *Template Method*

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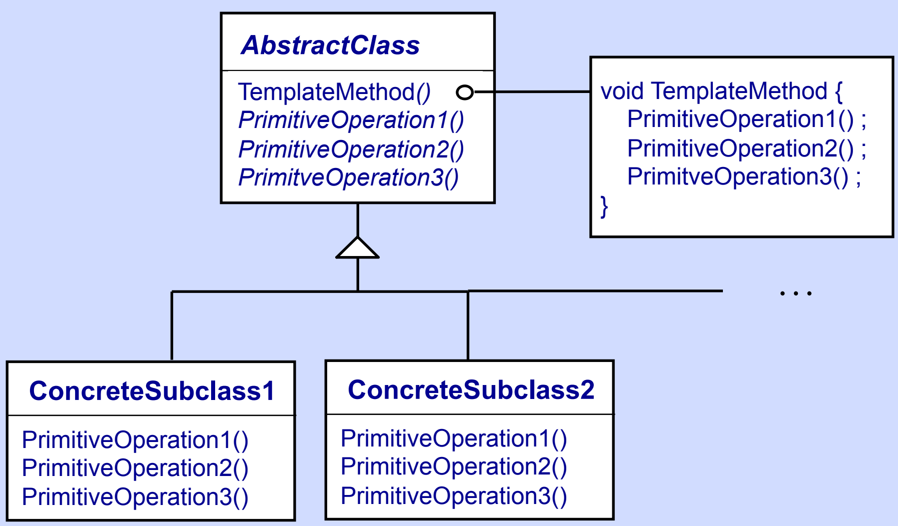
The *Template Method* design pattern



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Template Method: Motivation

- Context of application: Common sequence of operations, where each operation is specialized by subclasses
- Example: Drawing a widget in Android UI always involves 3 operations
  1. onMeasure()
  2. onLayout()
  3. onDraw()
- Different widgets (*View* subclasses) do each operation differently
  – But each widget repeats exactly that sequence of operations

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Template Method: Design

- Abstract superclass defines template method calling operation sequence
- Abstract superclass **declares abstract methods** for each operation
- Subclasses **define concrete methods** for each operation
- Execution sequence
  1. Subclass instance receives *TemplateMethod* call
  2. Superclass executes inherited *TemplateMethod* defined there
  3. Superclass's *TemplateMethod* calls each operation
  4. Operations in subclass of receiver are executed in the order specified by the template method
- Take advantage of message polymorphism (aka dynamic binding of messages and methods)

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Template Method: Consequences

- Useful when a bunch of subclasses must follow a common sequence of operations
- Each subclass gets to specialize how each operation is conducted
- Operations need not execute in strict sequence (conditional and iterative operations are possible)
- Again, possible because of dynamic binding of messages and methods
  - Calls to *PrimitiveOperations* from superclass's *TemplateMethod()* get kicked back down to subclasses

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AsyncTask's Java definition

- Generic class taking 3 type parameters:
  - *Params*: Type of parameters passed to async task upon execution
  - *Progress:* Type of progress units published by background thread
  - *Result*: Type of result
- *AsyncTask* subclass typically nested inside *Activity* class
- Example:
  - private class MyTask extends AsyncTask<String, Integer, Bitmap> { … }

  Source: http://developer.android.com/reference/android/os/AsyncTask.html
- Doc on Java variable parameter number:

  http://docs.oracle.com/javase/1.5.0/docs/guide/language/varargs.html

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Components of *AsyncTask* instance

- Typical *AsyncTask* subclass defines 4 key (protected) methods
  1. *onPreExecute()*
  2. *doInBackground()*
  3. *onProgressUpdate()*
  4. *onPostExecute()*
- Methods automatically called by OS after *AsyncTask* instance receives *execute()* call
- Methods 1, 3 and 4 executed in UI Thread
- Method 2 (*doInBackground()*) executed in worker thread

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Components of *AsyncTask* instance

Four callbacks in lifetime of an *AsyncTask* instance

1. *onPreExecute()*: Callback automatically invoked before *doInBackground()*
   – Prepare for execution of background task
   – Run in UI thread, not *AsyncTask* thread (even though defined within *AsyncTask* subclass)
   – **void** return type, no input parameters
   – Typical action: set up a progress bar

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Components of *AsyncTask* instance

Four callbacks in lifetime of an async task (cont'd)

2. doInBackground(Params …): Result

Does background work

- Runs in *AsyncTask* thread
- Called right after *onPreExecute()* returns
- Input: Array of type declared by generic argument *Params* when *AsyncTask* subclass created
- Output: Type declared by generic argument *Result*
- Can call *publishProgress(Progress …)* to update UI thread on current progress
- Example: `protected Bitmap doInBackground(String… strings) {`

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Components of *AsyncTask* instance

Four callbacks in lifetime of an async task (cont'd)

3. onProgressUpdate(Progress…): **void**

Update progress display

- Runs in UI thread whenever *doInBackground()* calls *publishProgress()* (in background thread)
- Typical action: Update progress bar
- Input parameters of type specified by generic argument *Progress* when *AsyncTask* subclass was defined
- Example: `protected void onProgressUpdate(Integer… values)`

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Components of *AsyncTask* instance

Four callbacks in lifetime of an async task (cont'd)

4. onPostExecute(Result): **void**

- Runs in UI thread after *doInBackground()* returns
- Result value returned by *doInBackground()* is automatically passed as input parameter to *onPostExecute()*
- Example: `protected void onPostExecute(Bitmap result)`

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Use case of an *AsyncTask*

1. UI thread creates instance of (subclass of) *AsyncTask*
2. UI thread sends message *execute()* to *AsyncTask* instance
   - *execute()* args automatically passed to *doInBackground()*
3. Appropriate callbacks automatically called by OS (do not call any of them)
   - *onPreExecute()* – Run in UI thread before *doInBackground()*
   - *doInBackground()* – Run in *asyncTask* thread
   - *onProgressUpdate()* (zero or many times) – Run in UI thread after each *publishResult()* call in *doInBackground()*; argument(s) automatically passed to *onProgressUpdate()*
   - *onPostExecute()* – Run in UI thread after *doInBackground()* returns

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Caveats on *AsyncTasks*

- *AsyncTask* instance **must** be created in UI thread
- Method *execute()* must also be called from UI thread
- **Each *AsyncTask* instance can only be executed once**
  - If multiple executions needed, create new instances
- Convenience advice: Nest *AsyncTask* class inside activity class
  - That way, *onPreExecute(), doInBackground()* and *onPostExecute()* will have access to UI fields that async task is likely to access and modify (e.g., in *onPostExecute()*)
  - If separate class used, then use getter and setter methods
- Either way, **beware of data races and deadlocks between async task and UI thread**

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The benefits of *AsyncTasks*

- Support for forking and joining a background thread
- Support for passing input objects (of type *Params…*) to background thread
- Support for obtaining result value (of type *Result*) from background thread
- Support for posting progress indications (of type *Progress…*) from background thread
- Note: *Params* and *Progress* are variable arg type, *Result* is not
- Note II: Remember to keep track of different threads executing code in same file
  - Multiple flows of control in same class makes programming more exciting

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The drawbacks of *AsyncTasks*

- In Java inner class instance gets implicit reference to fields of outer class
  - Typically, async task gets reference to fields of activity instance that creates async task
- If a configuration change occurs, activity will be paused, stopped and destroyed while async task is running
  - A new activity will be created, started and resumed
- However, old activity instance won't be deleted because async task still running and referencing fields of that activity
  - This is a (big) memory leak
- Worse yet, results of async task's execution will be posted on destroyed activity, not the new activity

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The drawbacks of *AsyncTasks* (cont'd)

- The moral of the story:
  - If activity destroyed while task running, async task causes memory leak
  - Updates and result of async task will go to the wrong activity
- Consequence: Configuration changes are not automatically supported
  - Use async tasks only for very short background chores (< 2 seconds)
  - Make sure to handle configuration changes yourself
  - A good solution: Start *AsyncTask* from fragment, call *setRetainInstance(true)* on fragment, refer changes back to fragment
  - See, e.g., http://www.androiddesignpatterns.com/2013/04/retaining-objects-across-config-changes.html

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Sidestepping memory leaks in *AsyncTasks*

1. Declare *AsyncTask* subclass *static*
   - Subclass instance no longer holds reference to outer class
   - But now *AsyncTask* subclass can no longer reference non-static fields in enclosing activity
2. Pass needed fields to subclass constructor, assign to subclass fields
   - If fields are *Views*, they will still retain a reference to their context
   - The memory leak is still possible!
3. Turn subclass subclass fields into *weak references*
   - Weak references do not prevent garbage collection!
   - Also, check that references to fields have not become **null**
   - https://medium.com/freenet-engineering/memory-leaks-in-android-identify-treat-and-avoid-d0b1233acc8

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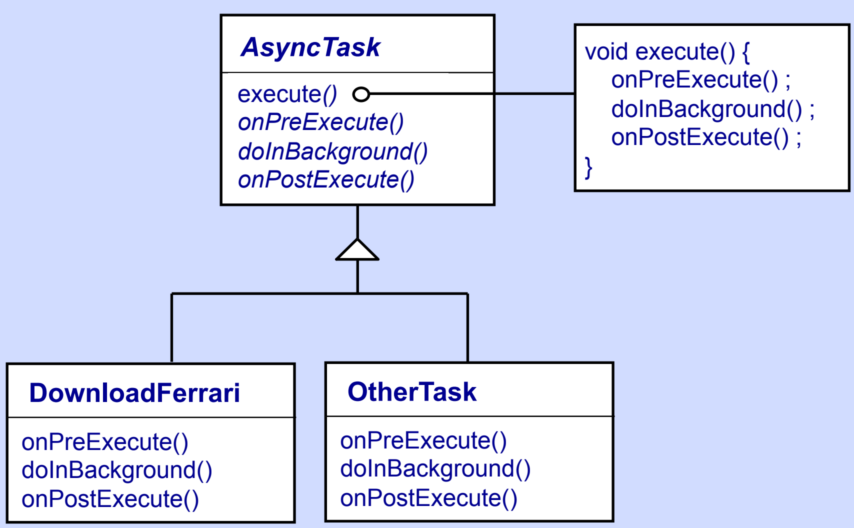
Async tasks and *Template Method*



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Classes *Handler, Looper,* and *MessageQueue*

- Support division of labor between any two arbitrary threads
  - *AsyncTask* only covered case of UI thread and a background thread
- Structure
  - A worker thread *T* can have a *Looper* and associated *MessageQueue*
  - Thread *T* creates one or more *Handler* instances associated with its message queue
  - Other threads use *T*'s handlers to add requests on *T*'s message queue
  - *T*'s looper takes requests from *T*'s message queue and executes them
- https://developer.android.com/reference/android/os/Handler.html
  https://developer.android.com/training/multiple-threads/communicate-ui#java

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Relating loopers, message queues, and handlers

- A thread can have at most one looper and message queue
  - UI thread comes with looper and message queue
  - Looper and message queue must be created for worker threads
  - 1-to-1 correspondence among thread, its looper and message queue
- A thread with a looper and message queue can have zero, one or many handlers
- Each handler is associated with just one thread

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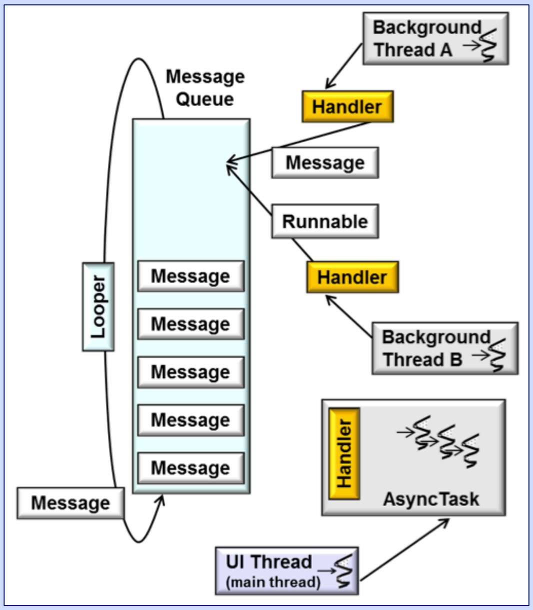
The looper and message queue



Picture courtesy of Douglas C. Schmidt

Explanation:

Threads *A* and *B* send messages and post runnables on UI thread's message queue using UI thread's handlers.

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The thread looper

- By default a thread does not have a *Looper* (except for UI thread)
  - Create and start one by calling *Looper.prepare()* and *Looper.loop()* in thread that wants looper
  - 1-to-1 correspondence among thread, its looper and message queue
- Looper executes a continuous loop in which it…
  1. Checks thread's message queue
  2. If not empty, dequeues first job
  3. Dispatches job to appropriate method
- Implementation: Check out *Looper* and *MessageQueue* classes

  https://developer.android.com/reference/android/os/Looper.html

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Use case of *Handlers* and *Message Queues*

Use case of client and server threads

1. Server thread *S* creates and starts looper
2. Thread *S* creates handler on its looper
3. Client (e.g., an activity) running in thread *A* gets reference to *S*'s handler
4. Client uses handler to adds job to *S*'s message queue
5. Looper in *S* dequeues job and runs it
6. Client gets result from handler

Messages and Runnables

- Job in message queue can be either a **message** or a **runnable**
- Terminology:
  - **Send** a message
  - **Post** a runnable
- An implementation of the *Active Object* design pattern, which builds upon the *Command* pattern by the Go4
- Goal: Decouple method invocation from method execution in concurrent system
- Threads communicate by adding tasks on each other's job queues
- Caveat: Threads already exist
- Source: https://developer.android.com/reference/android/os/Handler.html

Handlers, loopers and design patterns

- *Active Object* design pattern
  - Invented by Greg Lavender and Doug Schmidt
- *Active Object* is an extension of *Command* pattern from Go4 system
- ~~Let's see *Command* first, then *Active Object*~~
- Highly recommended video: https://www.youtube.com/watch?v=U9Tf7h-etl0

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Command pattern: The problem

Not Covered

- Suppose you are designing a system with a GUI (e.g., WYSIWYG editor)
- Build support for user-invoked commands (e.g., cut, paste, save, etc.)
- Requirements:
  1. Different commands have different interfaces
  2. Same command can be invoked in different ways by user
  3. Some commands should support Undo and Redo, others do not
- Obvious solution: Associate operations with user interface widgets!
- Of course, this is BAD, BAD, BAD
  - No support for (2) and (3) above (code duplication likely)
  - Also, proliferation and coupling of classes (each command likely to be implemented by several classes)

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Command pattern: Solutions

Not Covered

- An improved solution
  - Action-performing views are subclasses of a special *View* subclass that takes command
  - Instances of *View* subclass can parameterize command execution by defining an *execute()* method that carries out the command
- Problems still:

1. Passing context to the command function (e.g., different commands will have different interfaces)
2. Undo and redo not adequately supported yet

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Command pattern: Solutions (cont'd)

Not Covered

- Key idea: Associate an object, rather than a function, with each widget that can execute a command
  - Object is instance of a *Command* abstract class
  - *Command* instances embed executable code
  - *Command*'s API has *reversible()* method that returns boolean value
  - *Command*'s API has *execute()* method causing execution of code in command
  - Reversible *Command*s also remember previous state (e.g., before moving an object)
  - Store command history in a list

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The *Command* pattern

Not Covered

Name

Command or *Action* or *Transaction*

Applicability

- Parameterize objects by actions they perform
- Specify, queue, and execute requests at different times
- Support undo functionality by storing context information in command instances
- Support change log for recovery purposes
- Specify a transaction-based system (e.g., a database)

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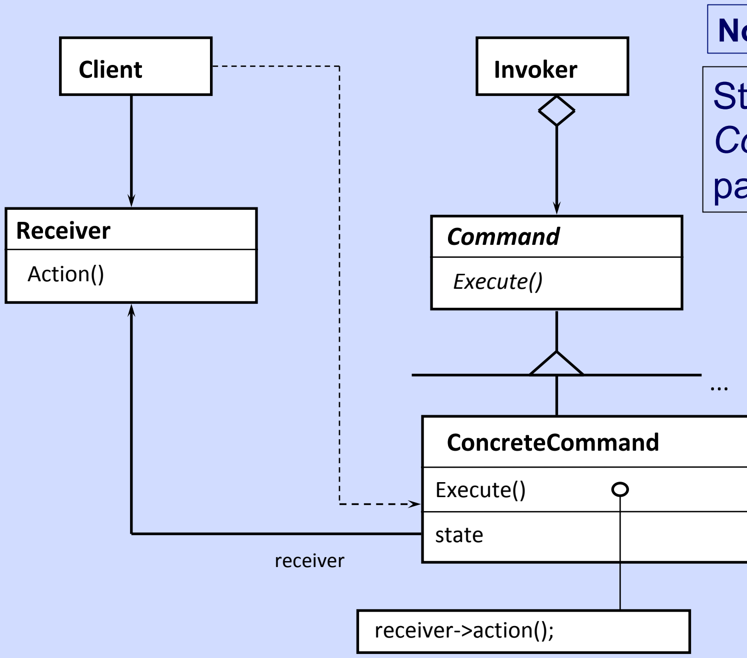
Not Covered

Structure of *Command* pattern



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The *Command* pattern

Not Covered

Consequences:

1. Decouple object receiving a request from object carrying out request
   – Editor example: Different icons can be associated with the same command
2. Commands are first class objects
   – Easy to support *undo* and *redo* functionality (e.g., add state info to commands to avoid error hysteresis)
   – Copying of command objects may be required
3. Use simple commands to form complex ones (e.g., support for editor macros)
4. Easy to extend commands (not tied to interface)

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The *Active Object* pattern

Name

Active Object or *Concurrent Object* or *Actor*

Applicability

- Clients accessing objects running in a different thread of execution

Goals

- Avoid blocking a server if a request is delayed
- Simplify synchronized access to a shared object
- Leverage concurrency available at hardware level

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The *Active Object* pattern (cont'd)

Solution

- Decouple method invocation from method execution
- Call looks like normal call, forwarded to different thread under the hood

Participants

- Client—Performs method invocation
- Activation queue—Holds pending requests (invocations)
- Scheduler—Decides which request to service next
- Servant—Executes method requests
- Future—Returns results of servant execution to original requestor

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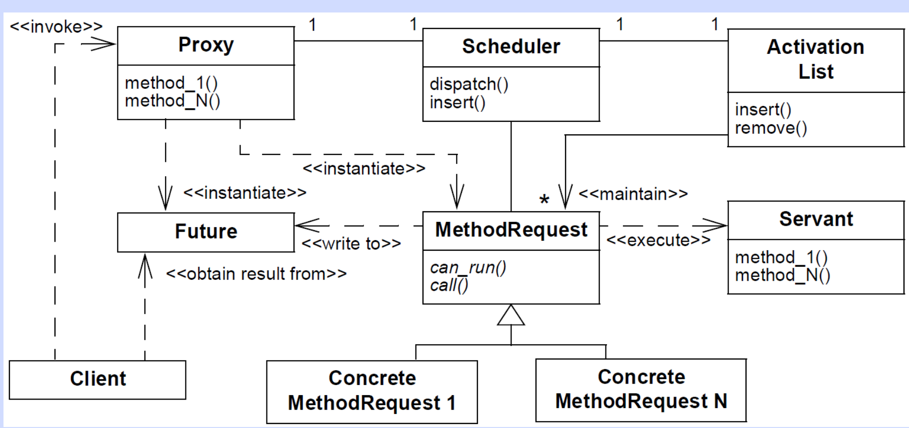
Structure of *Active Object* pattern

Picture courtesy of Douglas C. Schmidt



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Advantages of *Active Object* pattern

- Simplify complexity of interthread synchronization and communication
  - Remote calls are transparent to caller (looking like local calls)
  - No worries about sockets or object locking, etc. as long as communicating threads operate in their own address space (no object sharing)
- Take advantage of multicore hardware
  - Create a thread pool and spawn threads for different computations
- Support scheduling of operations at future times
- But: Beware of run-time overheads
  - Context switches
  - Dynamic memory allocations (no buffer sharing between threads)
  - CPU cache updates

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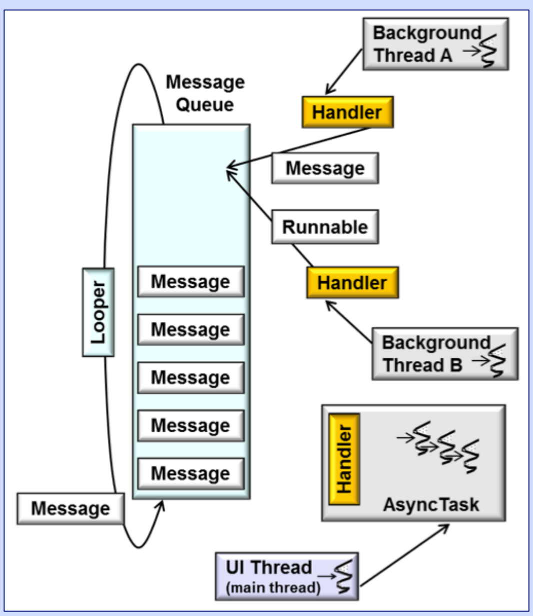
Recall looper diagram...



Picture courtesy of Douglas C. Schmidt

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Setting up a looper in a worker thread

Use case of server thread:

1. Call *Looper.prepare()* to set up looper
2. Create one or more *Handlers* associated with this looper
3. Call *Looper.loop()* to start processing jobs in the looper's queue
4. Call *Looper.quitSafely()* to stop processing jobs
   – But currently posted jobs will be handled

Caveat:

- Attempting to set up multiple loopers in a thread causes a RT error
- UI thread comes with predefined looper
  – Just create handler(s), if needed

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Setting up a looper thread...

- Code skeleton for setting up a thread with a looper

  Source: https://developer.android.com/reference/android/os/Looper.html

```
class LooperThread extends Thread {
   public Handler mHandler;

   public void run() {
      Looper.prepare();

      mHandler = new Handler() {
         public void handleMessage(Message msg) {
            // process incoming messages here
         }
      };
      Looper.loop();  }
}
```

Create new *Thread* subclass.

First, create a looper and message queue.

Second, create a handler.

Third, start the looper.

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... Or using predefined class *HandlerThread*

- *HandlerThread* = *Thread* subclass that prepares looper automatically
- Use case:
  - Extend *HandlerThread* instead of *Thread*
  - Do not override method *run()* in your *HandlerThread* subclass
    - *HandlerThread.run()* defines and starts looper, must be executed
  - Specify thread actions in callback *onLooperPrepared()*
  - Subclass constructor must take a string argument (thread's name), pass string to superclass's constructor (i.e., *HandlerThread*'s constructor)
- https://developer.android.com/reference/android/os/HandlerThread
  https://developer.android.com/topic/performance/threads

Using a *HandlerThread*

- Skeleton code for *HandlerThread* subclass

```
class MyHandlerThread extends HandlerThread {
  Handler handler;
  public MyHandlerThread(String name) {
    super(name);
  }
  protected void onLooperPrepared() {
    handler = new Handler(getLooper()) {
      public void handleMessage(Message msg) {
        // process incoming messages here
        // this will run in non-ui/background thread
      }
    };
  }
}
```

Create *HandlerThread* subclass.

Class constructor.

After looper in place attach *Handler* to it.

Relevant *HandlerThread* source code

- *HandlerThread*'s *run()* method creates looper and starts it; don't override!
  - From jellybean/frameworks/base/core/java/android/os/HandlerThread.java:51—62.

```
class HandlerThread extends Thread {
  ...
  public void run() {
    mTid = Process.myTid() ;
    Looper.prepare() ;
    synchronized(this) {
        mLooper = Looper.myLooper() ;
        notifyAll() ; }
    Process.setThreadPriority(mPriority) ;
    onLooperPrepared() ;
    Looper.loop() ;
    mTid = -1 ;
  }
}
```

Definition of *HandlerThread* class.

The *run()* method prepares and starts the new thread's looper.

Also notify any clients that might be doing *wait()* on this thread.

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Messages vs. runnables

- When job dequeued
  - If job is a runnable, call method *run()* on it
  - If job is a message, dispatch to method *HandleMessage()*
- Runnable: Same as before, implements *Runnable* Java interface by defining a *run()* method
- Message: Data structure carrying information about:
  1. Operation to be performed
  2. Operation's data
- Use a runnable when you know exactly what target thread must do; use message otherwise
- https://developer.android.com/reference/android/os/Message

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The *Message* structure

- Messages are instances of class *Message*
- *Message* contains following **public** fields
  - *what* – Integer opcode, mutually agreed upon by message sender(s) and receiver thread
  - *obj* – Arbitrary data object
  - *arg1, arg2* – Additional integer values
- Additional key fields (package default access)
  - *data – A Bundle* specifying additional data to be sent
  - *target* – A *Handler* intended to receive this message
  - *callback* – The *Runnable* executed when message is handled
- Source code: https://android.googlesource.com/platform/frameworks/base/+/pie-release/core/java/android/os/Message.java

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Message instance creation

- Two convenient ways to create instance of *Message* class
  1. Static message *Message.obtain()*
     - Returns message instance from global pool
     - Wildly overloaded with different initializers for return message
     - http://developer.android.com/reference/android/os/Message.html
  2. Use instance message *aHandler.obtainMessage()*
     - Similar behavior to *Message.obtain()*, but also sets target handler to *aHandler*
     - Again, multiple overloadings available

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Message behavior

- Key *Message* methods
  - *getTarget(), setTarget(Handler)* – Getter + setter for message's target (a *Handler* instance)
  - *setData(Bundle), getData()* – Getter + setter for additional data (as a *Bundle*)
  - *sendToTarget()* – Sends message to target *Handler*
  - Public fields are typically accessed directly by clients

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Relevant *Handler* methods

- *post(Runnable)* – Adds runnable to receiver (*Handler* instance)
  - Use only for runnables
- *postDelayed(Runnable, long)* – Adds runnable to receiver (*Handler* instance) but delay execution by specified number of ms
  - Use only for runnables
- *postAtTime(Runnable, long)* – Adds runnable to receiver (*Handler* instance) at time specified by second argument in ms
  - Second arg == uptime (could be delayed by sleep time)
- *postAtFrontOfQueue(Runnable)* – Adds runnable to front of receiver's queue
- See: http://developer.android.com/reference/android/os/Handler.html

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Relevant *Handler* methods (cont'd)

- *sendMessage(Message)* – Adds message to receiver (a *Handler* instance)
  - Use only for messages
- *sendMessageAtFrontOfQueue(Message)* – For urgent messages?
- *sendMessageDelayed(Message, long)* – At uptime (ms)
- *sendMessageAtTime(Message, long)* – After delay (ms)
- See: http://developer.android.com/reference/android/os/Handler.html

The looper's role

- Dispatch messages and runnables in handler queue to appropriate destination
- Runnable: Just dequeue *Runnable* from handler queue and call *run()* method in receiving thread
- Message: Call method *handleMessage()* of *Handler* in receiver's thread
  - Sender wants an operation to be run in thread of receiving handler
- *sendMessage(Message)* – Adds message to receiver (a *Handler* instance)
  - So, use either *handler.sendMessage(message)* or *message.sendToTarget()* to send message to handler

Use case: Posting runnable to handler

Suppose thread A wants some work done in worker thread B

1. Thread A creates a runnable
2. Thread A uses some kind of "post" method to place runnable on thread B handler queue
3. Thread B's looper eventually dequeues runnable
4. Thread B executes runnable, as per thread A's wish

- Doc: http://developer.android.com/reference/android/os/Handler.html
- Source: https://android.googlesource.com/platform/frameworks/base/+/pie-release/core/java/android/os/Handler.java

Message handling

- Typical structure of *handleMessage()* is a big **switch** statement, based on *message.what()*
  - From *MediaPlayerService.java* in *Music* app

```
private Handler mMediaplayerHandler = new Handler() { …

   public void handleMessage(Message msg) {
     switch (msg.what) {
     case SERVER_DIED:
          if (mIsSupposedToBePlaying) {
             gotoNext(true); } …
             break;
     case TRACK_WENT_TO_NEXT:
          …
          break;
     case TRACK_ENDED:
          …
        break;
```

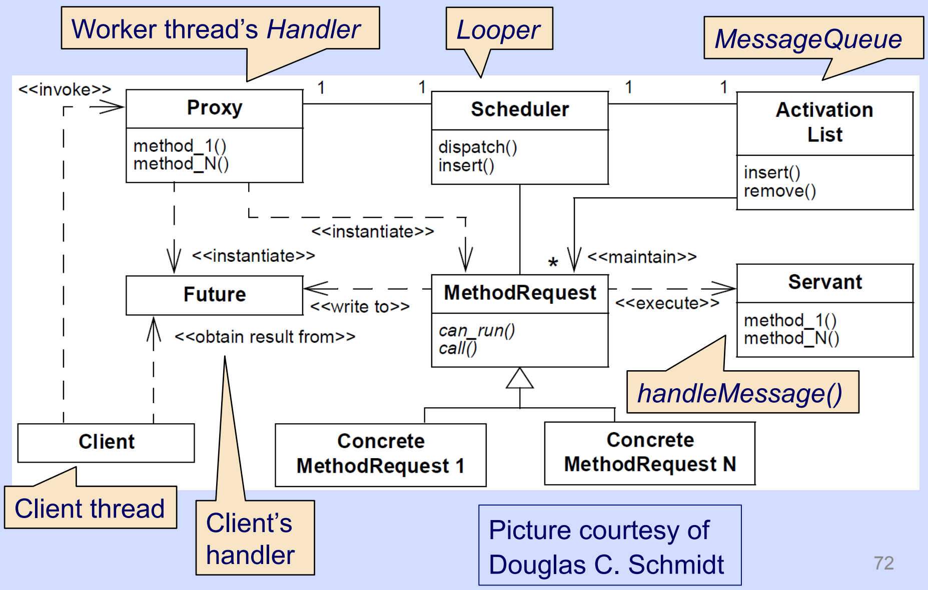
Create new *Handler*.

Define *handleMessage()* method.

Depending on *msg.what*, do different things.

Customary to use symbolic names for opcodes (*static final int*)

Handlers and *Active Object* pattern



Picture courtesy of Douglas C. Schmidt

Conclusions on *Handlers*

- A more powerful mechanism to use than *AsyncTasks*, but less convenient to use
  - *Messages* and *handleMessage()* seem to be used more often than *Runnables*
  - Sender thread can use runnable only when it knows exactly what work needs to be done by receiving thread

Summary of options for reporting to UI thread

Options for a worker thread to report computation results to UI thread:

- *View.post(Runnable)*
- *Context.runOnUiThread(Runnable)*
- Define, instantiate and execute an *AsyncTask*
- Use a *Handler* to communicate with UI thread
- Use ad-hoc Java synchronization

Other options available; these are just the most popular