Diagnosing and Fixing Memory Leaks in Web Applications: Tips from the Front Line

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Introduction

- **Mark Thomas**
- **Involved in Apache Tomcat for 7 years**
  - Wrote the first memory leak detection and prevention implementation for Tomcat
  - Implemented a large proportion of Servlet 3.0, JSP 2.2 & EL 2.2 for Tomcat 7
  - Currently the Tomcat 7.0.x release manager
  - Created Tomcat’s security pages
  - Committer, PMC member

- **Apache Software Foundation**
  - Member
  - Part of the infrastructure team

- **Staff Engineer at VMware**
  - Tomcat / httpd consulting and training
  - Lead the SpringSource security team
Agenda

- How it all started
- How memory leaks occur
- Debugging a leak – demonstration
- Root causes of leaks
  - Those already fixed
  - Future plans
- Questions
How it all started
How it all started

- Presenting on Servlet 3.0 / Tomcat 7 to an audience like this

- Made an off-the-cuff remark
  - “Permgen errors on reload are not caused by Tomcat bugs, they are caused by application bugs”

- That generated a lot of discussion

- Spent the rest of the conference debugging memory leaks with attendees
  - Tomcat wasn’t causing the leaks
  - Neither were the applications, at least not directly
  - Root cause often in JRE code, triggered by 3rd party library

- Wrote some fixes for the specific issues seen
How it all started

- Patterns soon started to emerge
- Realised that Tomcat could provide generic fixes
- Start of what became: `org.apache.catalina.core.JreMemoryLeakPreventionListener`
- Then ran some tests with some leaky applications
  - Spring sample applications
  - Test cases provided by users
  - A couple of internal web applications
- Added additional detection and prevention based on these
- The user community has provided additional ideas and feedback
How memory leaks occur
How memory leaks occur: A little theory

- A class is uniquely identified by
  - Its name
  - The class loader that loaded it

- Hence, you can have a class with the same name loaded multiple times in a single JVM, each in a different class loader

- Web containers use this for isolating web applications

- Each web application gets its own class loader

- Web application A can use Spring 2.5.6 whilst web application B can use Spring 3.0.2 without any conflicts

- Other containers, e.g. OSGI, use a similar approach

- Classes are loaded into the Permanent Generation
How memory leaks occur: Reference chains

- An object retains a reference to the class it is an instance of
- A class retains a reference to the class loader that loaded it
- The class loader retains a reference to every class it loaded

- Retaining a reference to a single object from a web application pins every class loaded by the web application in the Permanent Generation
- These references often remain after a web application reload
- With each reload, more classes get pinned in the Permanent Generation and eventually it fills up
Debugging a leak - demonstration

Apache Tomcat 7, YourKit Java Profiler, Simple web application
Debugging memory leaks

- Reload the application once
- Force GC
- Look for `org.apache.catalina.loader.WebappClassLoader` instances
- There should be exactly one per deployed application
- If you have more than that
  - look for the instance where `started = false`
  - trace its GC roots
  - that will tell you what is holding the reference
  - finding what created the reference might be harder
- A profiler makes this easy
- There are lots of good profilers available
  - Full disclosure: I use YourKit because they give me a free copy to use with Tomcat
Root causes

JRE triggered leaks
JRE triggered leaks

- All take a similar form
- Singleton / static initialiser
  - Can be a Thread
  - Something that won’t get garbage collected
- Retains a reference to the context class loader when loaded
- If web application code triggers the initialisation
  - The context class loader will be web application class loader
  - A reference is created to the web application class loader
  - This reference is never garbage collected
  - Pins the class loader (and hence all the classes it loaded) in memory
- Prevented by the JreMemoryLeakPreventionListener
JRE triggered leaks: sun.awt.AppContext

- **Triggered by**
  - Use of javax.imageio (e.g. Google Web Toolkit)
  - Use of java.beans.Introspector.flushCaches()
    - Ironically, Tomcat calls this to try and prevent memory leaks through the bean cache
    - Probably many others

- **Prevented in Tomcat by:**
  - Calling ImageIO.getCacheDirectory()
  - Pins Tomcat’s common class loader in memory
  - This is fine – don’t expect to throw this one away
  - Might be different if embedding Tomcat
JRE triggered leaks: sun.misc.GC.requestLatency(long)

- Starts a GC Daemon thread
- Thread’s context class loader will be context class loader when thread is started
- Triggered by:
  - javax.management.remote.rmi.RMIClassicServer.start()
  - Possibly others
- Prevented in Tomcat by:
  - Calling sun.misc.GC.requestLatency(long)
  - Has to use reflection
  - JVM specific so need to handle other JVMs
  - Pins Tomcat’s class loader in memory
  - Should be OK (remember embedding)
JRE triggered leaks: More threads

- Both very similar to previous slide
  - Starts an HTTP keep-alive thread
  - Triggered by URL. `openConnection()`
  - Prevented in Tomcat by loading the `sun.net.www.http.HttpClient` class
  - JVM specific
- **Java Cryptography Architecture**
  - Starts a Token poller thread
  - Triggered by creating a message digest (under certain conditions)
  - Prevented in Tomcat by calling `java.security.Security.getProviders()`
JRE triggered leaks: JarURLConnections

- URL connections are cached by default
- An open JarURLConnection locks the JAR file
- Affects all operating systems
  - Harder to ignore on Windows
  - Prevents web applications from being undeployed
  - Potential security risk

- Triggered by
  - log4j 1.2.15 and earlier
  - javax.xml.bind.JAXBContext.newInstance()

- Prevented in Tomcat by:
  - Disable caching by default
JRE triggered leaks: XML parsing

- Don’t know why this triggers a leak
- No GC roots reported by profilers
  - JVM bug
- Made it very difficult to track down
- Triggered by:
  - DocumentBuilderFactory.newInstance();
- Prevented in Tomcat by:
  - DocumentBuilderFactory.newInstance();
Root causes

Application triggered leaks
Application triggered leaks

- All take a similar form
- Application registers an object with a JRE provided registry
- JRE registry is loaded by the system class loader
- Not cleared when web application is reloaded
- Reference chain
  - Registry retains a reference to the object
  - Object retains a reference to its class
  - Class retains a reference to its class loader (web application class loader)
  - Class loader retains references to all classes it loaded

- Applications are responsible for clearing references they create
- Failure to do so is logged on application stop
Application triggered leaks: JDBC drivers

- JDBC drivers are automatically registered with java.sql.DriverManager
  - When loaded
  - Through the services API
- JDBC drivers are NOT automatically de-registered
- Applications must de-register JDBC drivers when stopped
- Use a javax.servlet.ServletContextListener
  - contextDestroyed() event
- Tomcat will de-register JDBC drivers if the applications forgets
Application triggered leaks: Threads

- Threads started by a web application will have the web application class loader as the context class loader
- Applications must stop threads they start
- Tomcat will log an error if applications forget
- Tomcat can try and stop the thread (requires configuration)
  - TimerThread via reflection – fairly safe
  - If started via an Executor via reflection– fairly safe
  - Thread.stop() – unsafe

- Stopping threads
  - Code is not thread safe
  - Often causes a JVM crash
Application triggered leaks: ThreadLocals

- The lifecycle of a ThreadLocal must match that of a request
- An application may never see a Thread again
  - No way to remove the ThreadLocal later
- Applications must clear any ThreadLocals they create in the same request
- Tomcat will log an error if applications forget
- Tomcat can try and clear the ThreadLocal (requires configuration)
  - Code is not thread safe
  - Not seen a problem in testing
Application triggered leaks: Non-application issues

- **sun.rmi.transport.Target**
  - Nothing the application can do to clear these
  - Tomcat does it silently via reflection

- **ResourceBundle**
  - Uses a weak reference
  - Still appears to trigger leaks
  - Tomcat clears the references silently via reflection

- **static final reference**
  - Not cleared by GC in some (very) old JVMs
  - Code still present
  - Disabled by default in Tomcat 7

- **Tomcat also clears references it creates**
  - loggers, introspection utils
Future plans
Future plans

- See https://issues.apache.org/bugzilla

- Bugs
  - Leaks triggered by JSP pages aren’t detected or cleared (48837)

- Enhancements
  - Generic solution to ThreadLocal issues
    Renew the thread pool after application reload (49159)
  - Add the start date when reporting leaks in the manager app (49395)

- Can we reduce the leak by somehow manipulating the class loader?
  - No success so far

- Keep 6.0.x in sync with new features as they are added to 7.0.x
  - 6.0.30 will have all the latest changes
Useful links
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- [http://wiki.apache.org/tomcat/MemoryLeakProtection](http://wiki.apache.org/tomcat/MemoryLeakProtection)

Mailing lists

- announce@tomact.apache.org
- users@tomcat.apache.org
- dev@tomcat.apache.org
Questions