Towards Memory Management for Service-Oriented RTS

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Overview

- Introduce service-oriented architecture (SOA)
- Motivation for integrating SOA with RTS (RT-SOA)
  - Dynamic reconfiguration
- Issue of memory management in RT-SOA
  - Issue of preconfigured GC
  - Issue of scoped memory and 3rd party services
- Dynamically reconfigurable GC
  - Reconfiguration analysis
  - Admission control
  - Reconfigurable GC
- Evaluation and conclusions

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Service-Oriented Architecture (SOA)

- A service is an act or performance offered by one party to another
- Similar to objects, modules, and components etc, but:
  - Dynamically discoverable
  - Dynamically available
- Service-Oriented Architecture (SOA) is a way of designing a software system to provide services:
  - To end-user applications
  - To other services
  - Achieved by using published and discoverable interfaces (Publish-Find-Bind)
- SOA enables application dynamic reconfiguration

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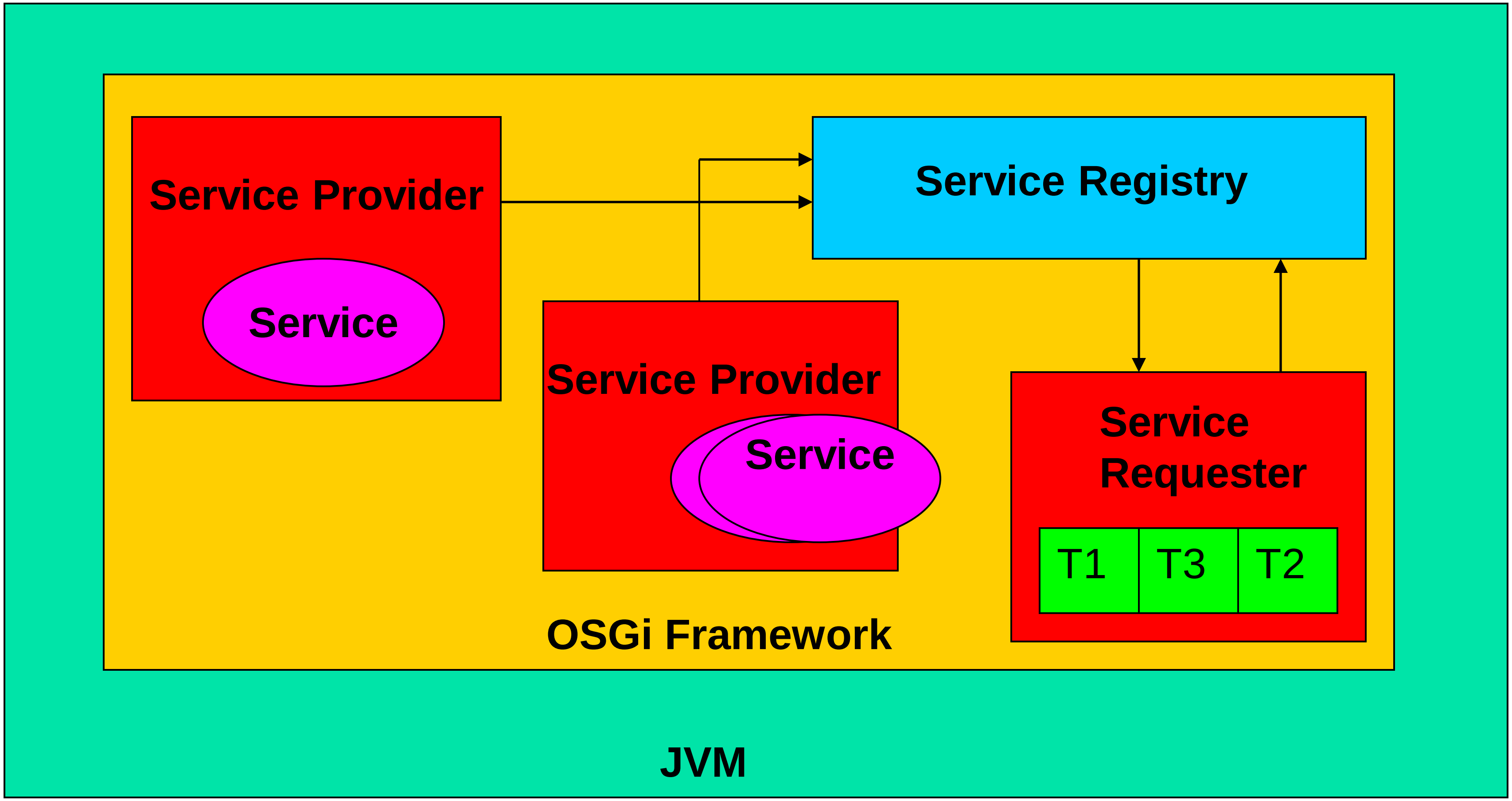
Dynamic Reconfiguration

- Dynamic reconfiguration
  - Enables the application architecture to be modified at run-time
  - Without shutting the application down
- Different SOA technologies offer different levels of application dynamic reconfiguration
  - The most basic level is service substitutability – i.e. the ability to bind with different service providers at run-time
  - OSGi Framework provides more powerful reconfiguration
- OSGi Framework
  - SOA dynamism – Can acquire new services and release services at run-time
  - CBSE with dynamism – Provides the ability to install, uninstall, and update components at run-time

Dynamic Reconfiguration Example



Motivation for SOA in Real-Time Systems

- Dynamic reconfiguration improves the system availability
  - System does not need to be taken offline to be maintained/reconfigured
  - Improves application availability
  - Important in RTS in particular as they have high availability requirements
- Dynamic reconfiguration minimises memory resource requirements
  - Only require the components and services comprising the current mode of operation to be deployed
  - Important in embedded systems (resource constrained)
- Remote controllability- evolving RTS from a remote location
  - RTS deployed in harsh environment- danger in being physically present in deployment environment for updating software
  - Software updates in mass produced embedded devices such as consumer electronics

Current GCs with Dynamically Reconfigurable Systems

Runtime

T_1 (C,T,D, A)

T_2 (C,T,D,A)

T_3 (C,T,D,A)

GC (C,T,D)

T_4 (C,T,D,A)

T_5 (C,T,D,A)

T_6 (C,T,D,A)

- Application reconfigured at run-time
- GC NOT reconfigured accordingly
- Risk of memory exhaustion

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Scoped Memory with Dynamically Reconfigurable Systems

- Scoped Memory (SM)
  - Avoids overheads of garbage collection (GC) and therefore suited to harder RTS
- Two approaches to using SM in SOA
  - Threads can enter scoped memory before calling services
    - IllegalAssignmentErrors if service method breaks RTSJ memory assignment rules
  - Services handle scoped memory
    - ScopedCycleExceptions depending on the scope stack of calling threads
    - Blocking – ensuring only one thread in SM at any one time
- We focus on GC not SM
  - RT-GC advancing, adequate for RT-SOA

Application Reconfiguration Example

Thread	C (ms)	T (ms)	D (ms)	A (MB)
T1	1	10	10	0.1
T2	2	8	8	0.3
T3	1	12	12	0.2
T4	1	5	5	0.5
T5	5	30	30	0.4
T6	1	18	18	0.01

T_{GC} = 8 ms
C_{GC} = 2.5 ms
M = 24.5 MB

- Perform application reconfiguration:
  - GC reconfiguration analysis
  - Application reconfiguration admission control
  - GC reconfiguration

Example – GC Analysis

- Estimate GC cycle work (W_{GC})
  - Computation time to complete a GC cycle
    - Cost of reference traversal (root-set, live objects)
    - Cost of object evacuation (copying)
    - Cost of memory initialisation

$$W_{GC} = c_1\left(\frac{R + \sum_{i=1}^{n} A_i}{sizeof(word)}\right) + c_2\sum_{i=1}^{n} A_i + c_3\left(\frac{H}{2}\right)$$

  - W_{GC} = 29.2 ms

Example – GC Analysis

- Calculate GC parameters
  - Find the maximum CPU utilisation for GC
  - GC period (T_{GC}) – equal to the application thread with the smallest period
  - GC budget (C_{GC}) – find maximum value of x such that all threads remain schedulable

$$C_{GC} = \max\left\{ x \mid \forall t \in \tau_{\{i=0\ldots n\}} : \left\lceil \frac{T_i}{T_{GC}} \right\rceil x + \sum_{j=1}^{i} \left\lceil \frac{T_i}{T_j} \right\rceil C_j \le D_i \right\}$$

  - $T_{GC} = 5\text{ms}$, $C_{GC} = 0.5\text{ms}$

Example – GC Analysis

- Calculate GC cycle time
  - During a GC period, the GC thread can only perform an amount of work equal to C_{GC}
  - Therefore a number of GC periods will be required to complete a GC cycle

$$R_{GC} = (T_{GC} - C_{GC}) + \left(\left\lceil \frac{W_{GC}}{C_{GC}} \right\rceil - 1 \right) (T_{GC} - C_{GC}) + W_{GC}$$

  - R_{GC} = 294.7 ms

Example – Admission Control

- Application reconfiguration admission control
  - Application's memory requirement is 2 * (worst case live memory plus garbage allocation in a GC cycle of worst case length)
  - As at end of a GC cycle, before semispace flip, both semispaces will have copies of live memory, and one GC cycle's worth of garbage alloc

$$M = 2\left(\sum_{i=1}^{n}\left(\left(\left\lceil \frac{R_{GC}}{T_i} \right\rceil + 1\right)A_i\right) + \sum_{i=1}^{n} A_i\right)$$

- Guarantees threads will not experience memory exhaustion
  - If free mem <= M then accept application reconfiguration and reconfigure GC
  - Else, reject application reconfiguration as it would cause memory exhaustion
- M = 93.9 MB

Example – GC Reconfiguration

- Reconfiguration analysis determines new C,T,D parameters for the GC
- Admission control controls application reconfiguration
- Need to reconfigure the GC with these parameters
- Only GC available that can be reconfigured is Sun's GC
  - Only the GC thread's priority can be modified, but not its C,T,D
- Solve by:
  - Setting GC thread's priority to a background priority
  - Creating a GC controller thread to manipulate the GC thread's priority such that it appears like a time-based GC
  - GC controller thread period = T_{GC}
  - Time GC runs at high priority = C_{GC}

Evaluation

Scenario	Expected result	Actual result
Single thread	Memory not exhausted (Reconfig analysis)	Garbage is collected. No memory exhaustion.
Several threads	Memory not exhausted (Reconfig analysis, Admission control)	Garbage is collected. No memory exhaustion Admission control functions correctly.
Dynamic unbounded structures	Eventually memory exhausted	Any garbage is collected, but memory is eventually exhausted.
Misbehaving thread	Memory not exhausted (Memory allocation enforced)	Misbehaviour is detected and the thread is blocked. No memory exhaustion

Conclusions

- Can develop dynamically reconfigurable RTS applications with:
  - GC Reconfiguration analysis
  - Admission control
  - Reconfigurable GC
  - Memory allocation enforcement
- No risk of garbage related memory exhaustion
- Dynamic reconfiguration:
  - Improves system availability
  - Reduces the memory requirement of application
- Beneficial to RTS as they typically have:
  - high availability requirements
  - resource constrained

Questions?