A Characterization of State Spill in Modern Operating Systems

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Advanced OS goals are challenging

Goal in OS literature	Impediments to that goal
Process migration	Residual dependencies on original system
Fault isolation/tolerance, software virtualization	Sprawl of states introduces fate sharing, complicates isolation & multiplexing logic
Live update and hot-swapping	Cannot modify individual entity in isolation; state transfer functions are non-trivial
Maintainability	Coupling remains despite modularization
Security	Loss of control over propagated data

State spill is the underlying cause

State spill is the act of a software entity's state **undergoing a lasting change** as a result of handling a transaction from another entity.

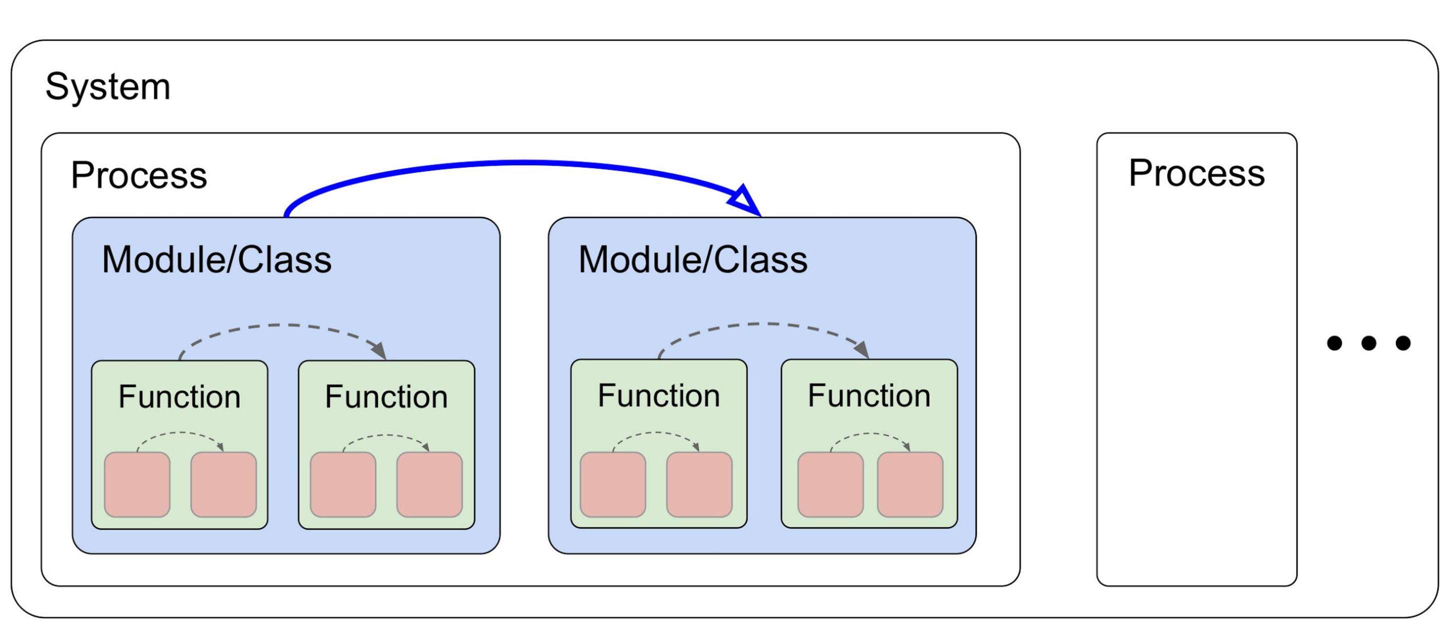
```
public class SystemService {
  static int sCount;
  byte mConfig;
  List<Callback> mCallbacks;
  int unrelated;

  public void addCallback(int id,
      byte cf, Callback cb) {
    int b = id;
    Log.print("id=" + b);
    this.mConfig = cf;
    this.mCallbacks.add(cb);
    sCount++;
  }
}
```

This method is a transaction handler invoked by application processes.

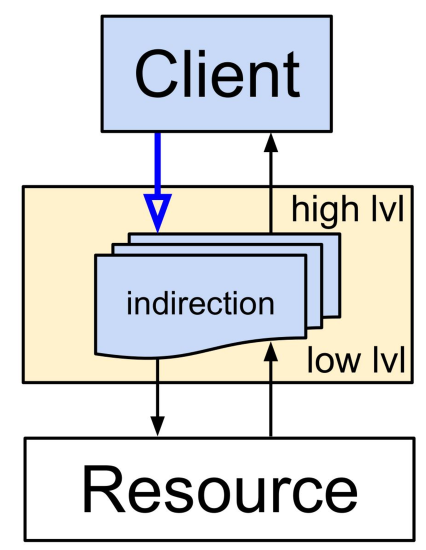
Entity granularity dictates state spill

State spill is relative to the chosen entity granularity. Low-level entity interactions (shaded) are unimportant.



Classification of state spill

Based on four common OS entity design patterns:

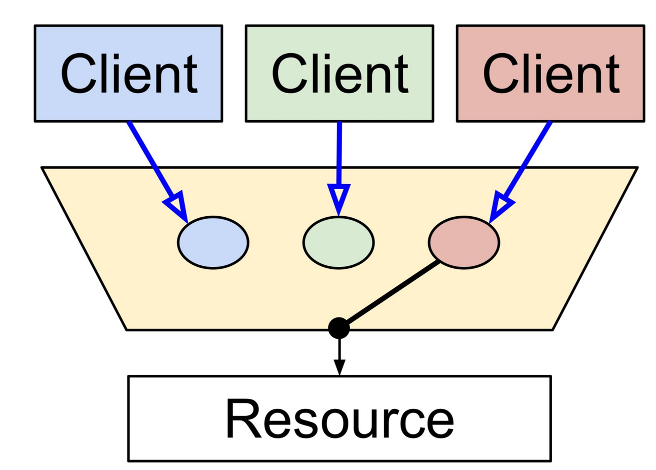


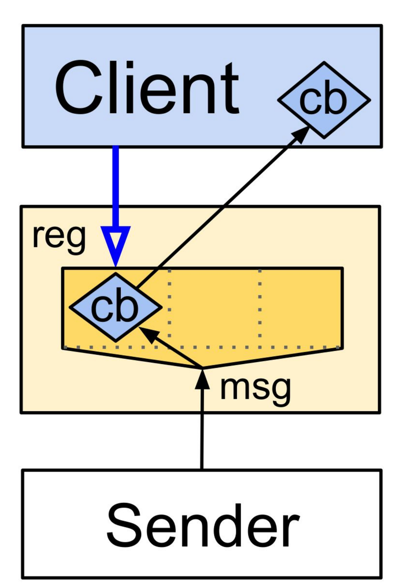
Indirection Layers convert between high-level and low-level representations of data and commands.

- Virtual File System abstraction
- Process abstraction
- Microkernel userspace servers
- Device drivers

Multiplexers temporally or spatially share an underlying resource among multiple clients.

- Schedulers / process mgmt
- Window managers
- High-level drivers



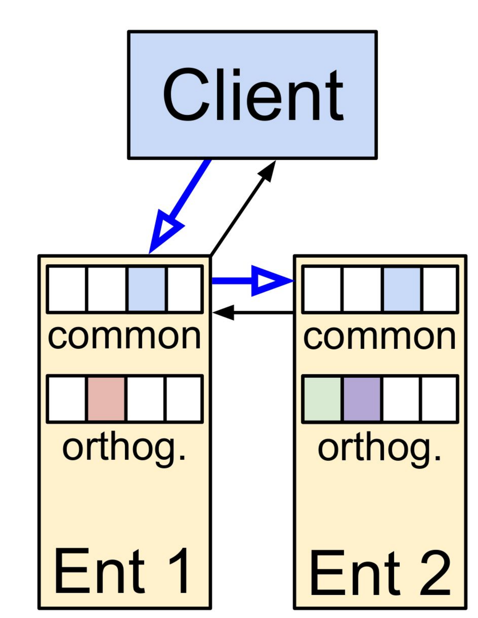


Dispatchers register client callbacks to properly deliver events or messages.

- Device event callbacks
- Synchronization primitives
- Upcalls
- IPC layers

Inter-Entity Collaboration requires synchronization of non-orthogonal states to ensure correctness.

- Microkernel userspace servers
- Android services

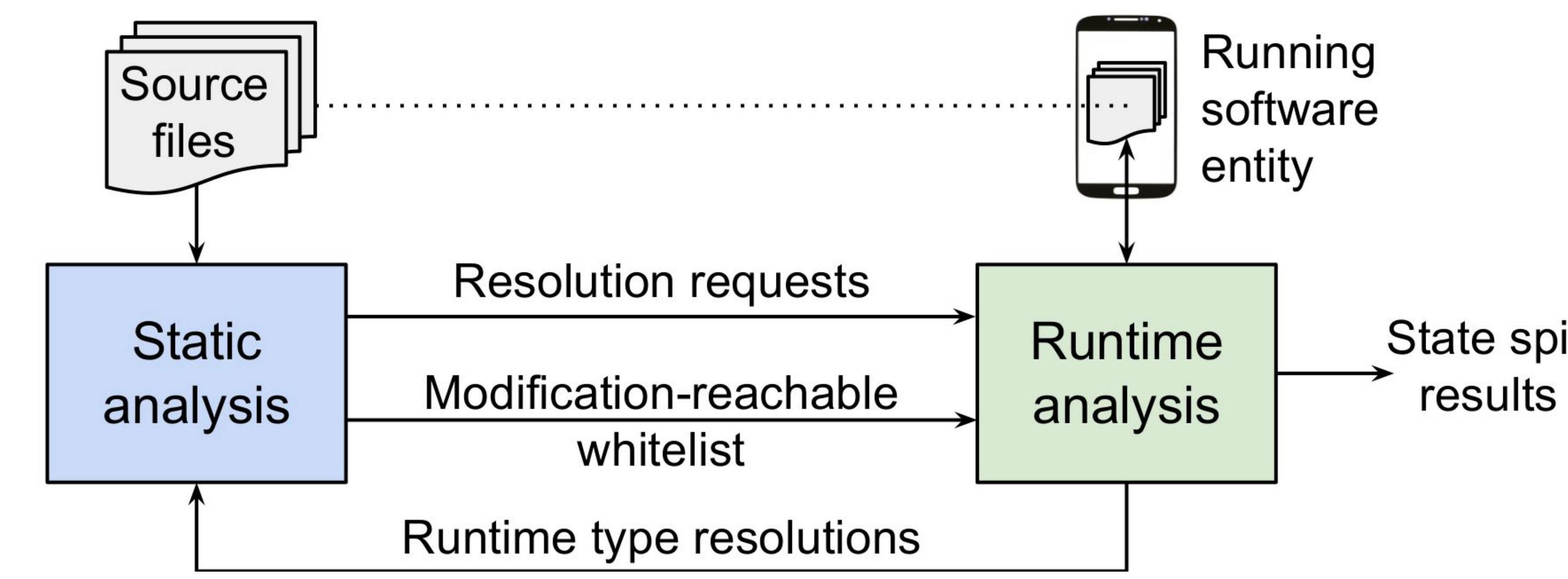


Designs to avoid state spill

- Client-provided resources
- Stateless communication
- Hardening of entity state
- Modularity without interdependence
- Separation of multiplexing from indirection

RESTful principles

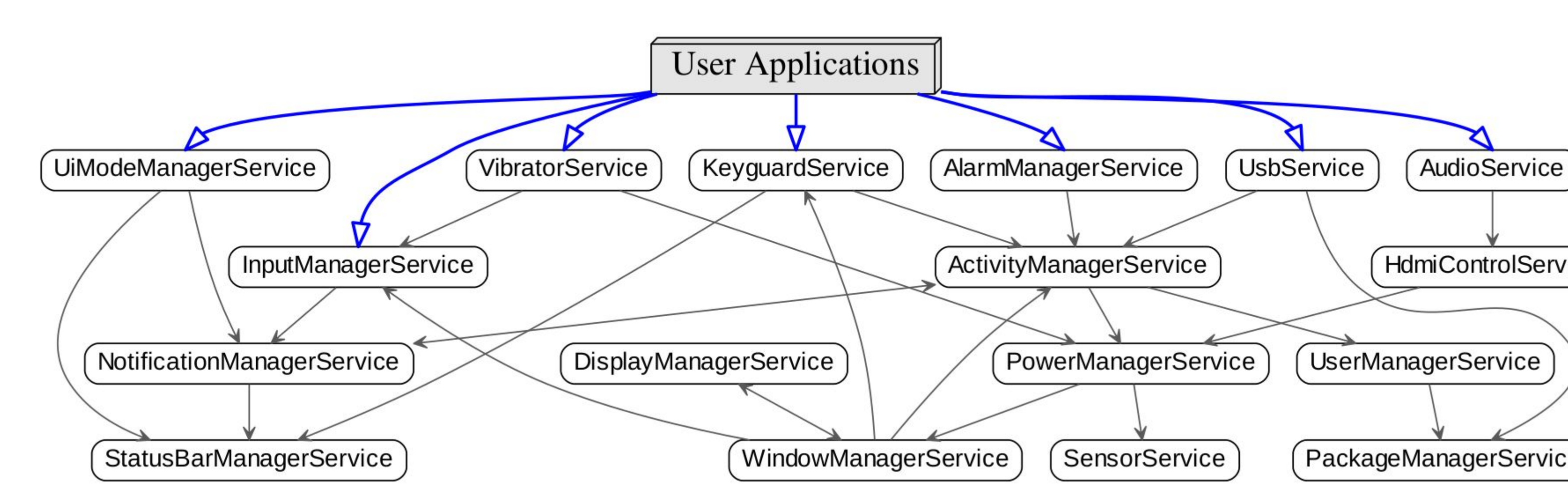
Automated detection with StateSpy



1) Detect *quiescent point* for safe analysis
   -- monitor transaction entry & exit points
2) Capture state of software entity
   -- key insight: use **debugging frameworks**
3) Difference captured states
   -- via existing tree comparison algorithms
4) Filter results with static analysis
   -- determine *modification reachability*

State spill in Android system services

- StateSpy found state spill in 94% of Android services analyzed, most with 1-10 instances
- Classified state spill instances in 60 transactions:
  - 39% caused by indirection layers
  - 21% caused by multiplexers
  - 55% from dispatchers/collaboration
- Better discovery of problems in app migration than manual identification of residual dependencies [1]
- Discovered *secondary spill* in 27 services:



[1] Alex Van't Hof, et al., *Flux: Multi-Surface Computing in Android*, EuroSys'15.