Graceful Failure During OOM Conditions

Embedded Systems

- Combo of hardware and software with specific purpose
- May be very simple or relatively complex
- Some run variants of linux
- Examples: remote sensors, medical devices, self driving car radar or gps, elevator control units, etc..

Memory Allocation And OOM Killer

- Linux intends for “good” malloc() calls never to fail
- If a mmap/malloc call fails due to lack of memory, OOM killer is activated
- The OOM killer tries to kill processes to free memory
- Complicated score to decide which process is killed, but primarily based on size of memory usage
- Adjusted OOM Score in proc fs allows user to make a process less likely (or impossible) to be killed by OOM killer
- But what if all killable processes have been killed?
- Deadlock, unresponsiveness, and system crash as OS processes fail due to bad memory allocation calls.

Memory, OOM, and Embedded Systems

- OOM conditions are less likely on embedded systems as workload is relatively well known and consistent. However…
- Overcommit may cause OOM
- Coding errors may cause memory leaks
- Fundamental mismatch between hardware and task

Handling OOM Conditions -- Graceful failure

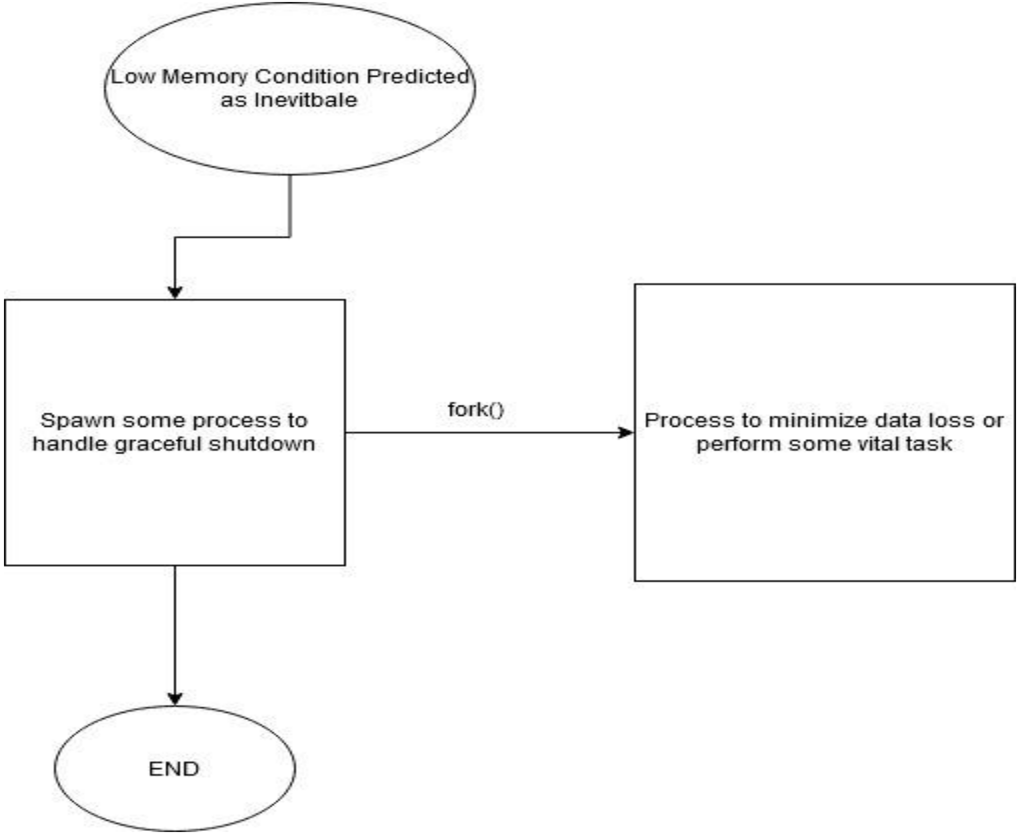
- Currently two options -- let OOM killer kill process or mark process as unkillable and hope system can kill other processes
- In some situations , it may be better for a process to fail and execute a “graceful shutdown” procedure rather than get killed by OOM killer, or cause an unresponsive state.
- Real-time Embedded Systems
    - Medical Devices -- shut down and notify user of failure
    - Data Loggers -- transmit data and then shut down
    - Self Driving Car Radar -- gently apply brakes and notify user to take over

Design Fulfillment

Three main components of pipeline:

1. Detection/Prediction of Out of Memory Condition
2. Minimising Data Loss / Barebone Functionality
3. Graceful Shutdown

Spawning Processes

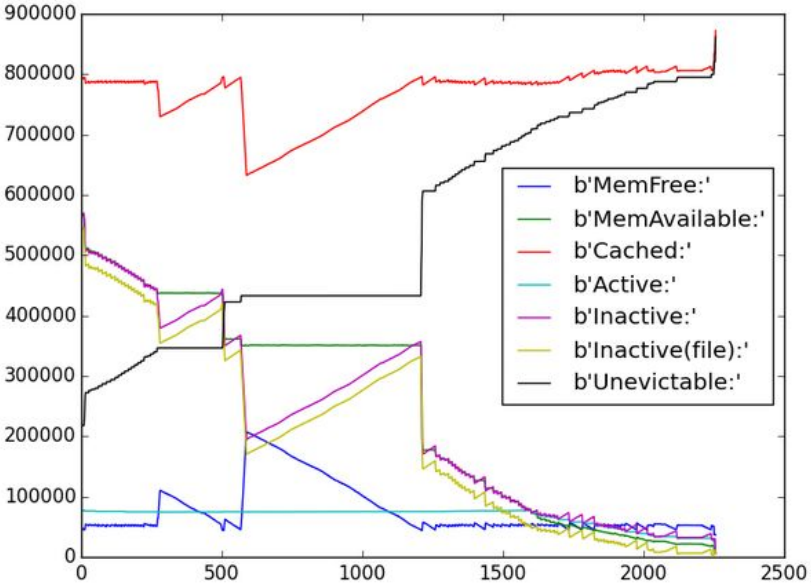

Low Memory Condition Predicted as Inevitbale
Spawn some process to handle graceful shutdown
fork()
Process to minimize data loss or perform some vital task
END

Spawning Processes cont’d

System Function	Process to Spawn
Data Logging	Write data stream to file
Safety Critical	Barebone Functionality
Monitoring Equipment	Raise Alarm

Predicting Out of Memory Condition

- Gather Statistics
  - OOM Scores
  - CPU Load
  - /proc/meminfo
- Combination of Factors
- Kickstart Pipeline
  - Minimise Data Loss
    - Or Barebone Functionality
  - Graceful Shutdown



Graceful Shutdown

Three main components of pipeline:

1. Detection/Prediction of Out of Memory Condition
2. Minimising Data Loss / Barebone Functionality
3. Graceful Shutdown
    a. Complete any other critical safety-measures
    b. Call custom shutdown procedure, SIGTERM, SIGKILL?

Graceful Shutdown

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Graceful Shutdown

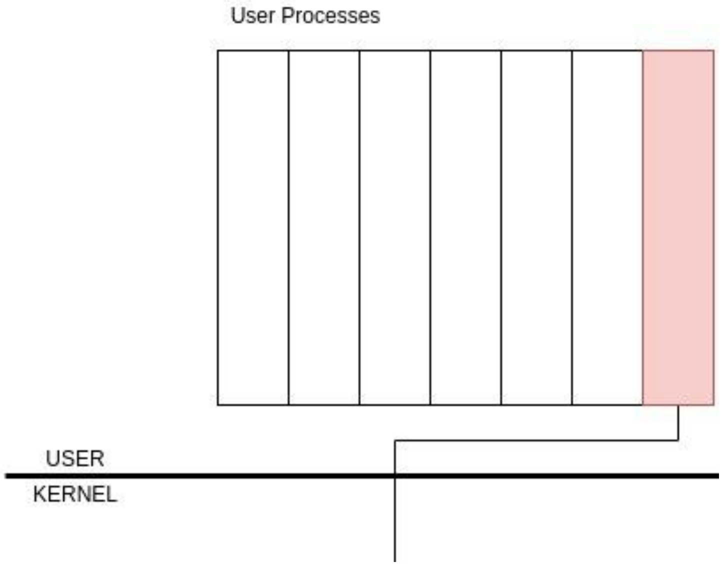
Current Proposed Solutions

- Kernel Process related to SIGTERM or SIGUSR1
- LKM / System Call Intercept

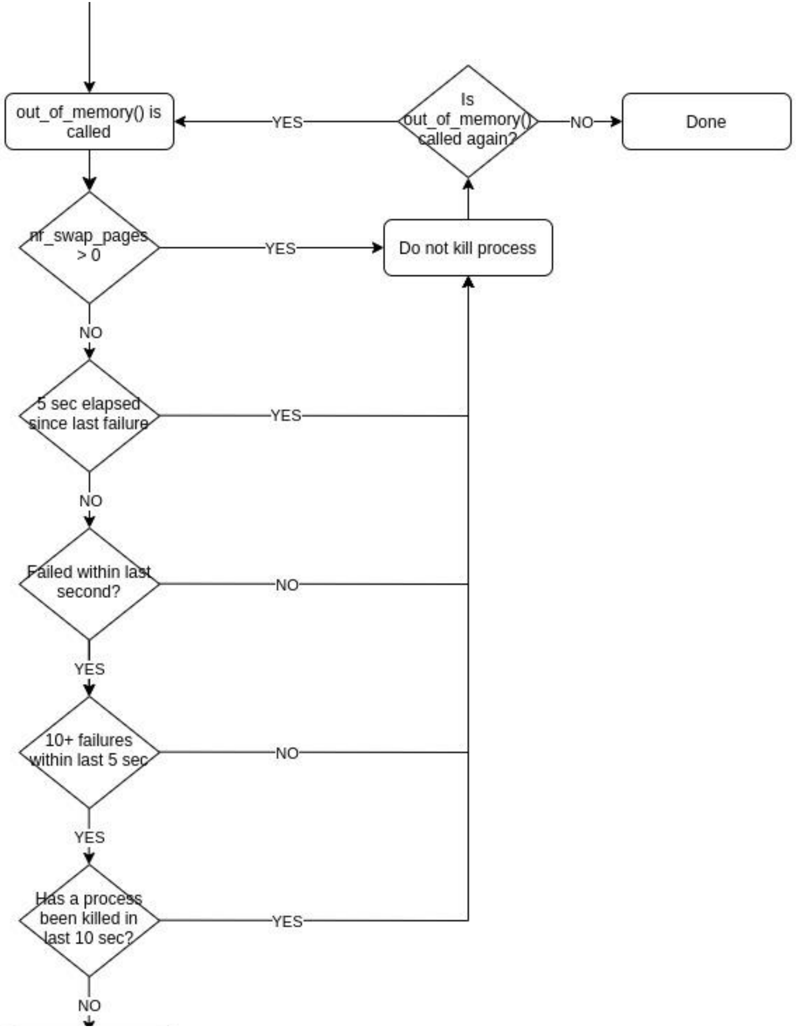
Solution Requirements

- Customizable across platforms / OS
- Has access to user-level process info and kernel-level

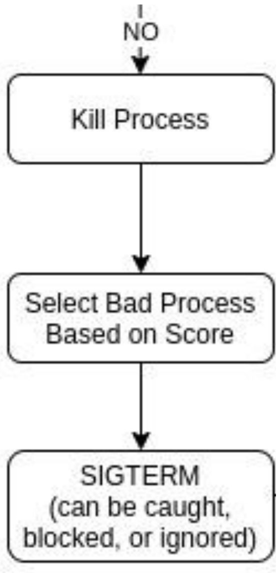
Graceful Shutdown



Graceful Shutdown


out_of_memory() is called
YES
Is out_of_memory() called again?
NO
Done
nr_swap_pages > 0
YES
Do not kill process
NO
5 sec elapsed since last failure
YES
NO
Failed within last second?
NO
YES
10+ failures within last 5 sec
NO
YES
Has a process been killed in last 10 sec?
YES
NO

Graceful Shutdown



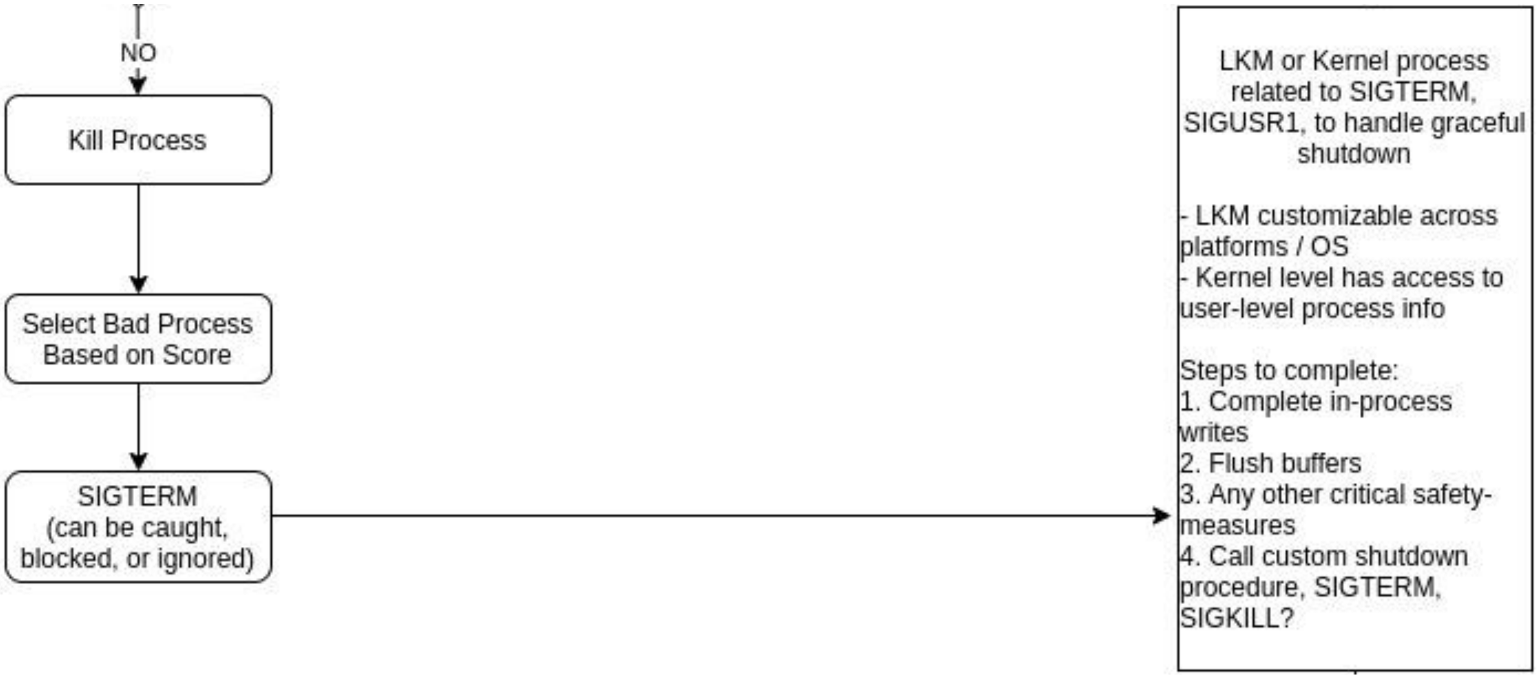
NO

Kill Process

Select Bad Process Based on Score

SIGTERM
(can be caught, blocked, or ignored)

Graceful Shutdown



NO

Kill Process

Select Bad Process Based on Score

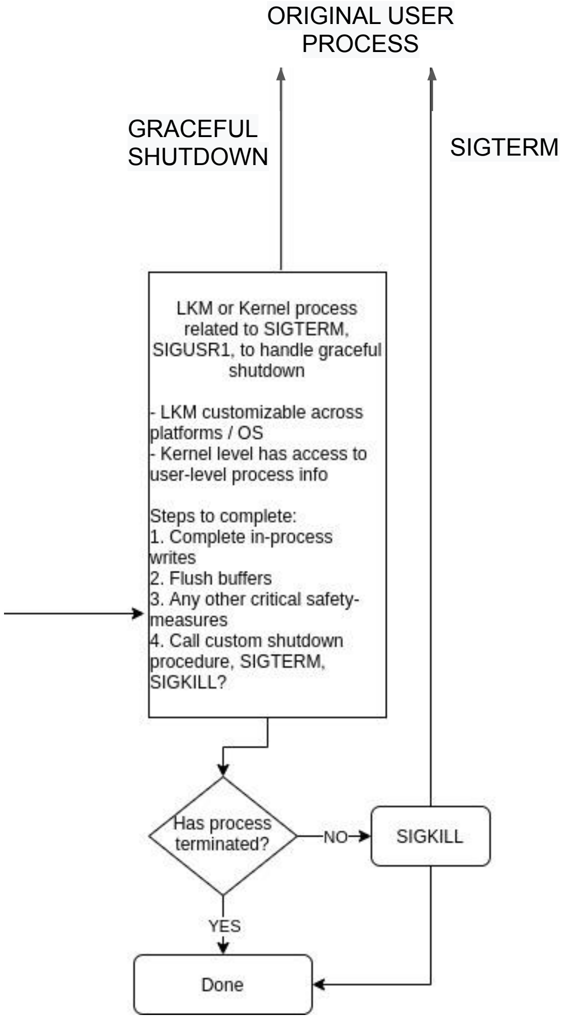
SIGTERM (can be caught, blocked, or ignored)

LKM or Kernel process related to SIGTERM, SIGUSR1, to handle graceful shutdown

- LKM customizable across platforms / OS
- Kernel level has access to user-level process info

Steps to complete:
1. Complete in-process writes
2. Flush buffers
3. Any other critical safety-measures
4. Call custom shutdown procedure, SIGTERM, SIGKILL?

Graceful Shutdown



ORIGINAL USER PROCESS

GRACEFUL SHUTDOWN

SIGTERM

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Steps to complete:
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4. Call custom shutdown procedure, SIGTERM, SIGKILL?

Has process terminated?

NO

SIGKILL

YES

Done

Graceful Shutdown - Method Pro / Con

LKM / System Call Intercept

PRO

- Wraps existing functionality
- Speed (as compared to process)
- Can still invoke kernel process if needed
- Users do not need to rebuild kernel

CON

- Complexity of newer kernel security
- Memory fragmentation
- Loaded late in boot cycle

Kernel Mode Process

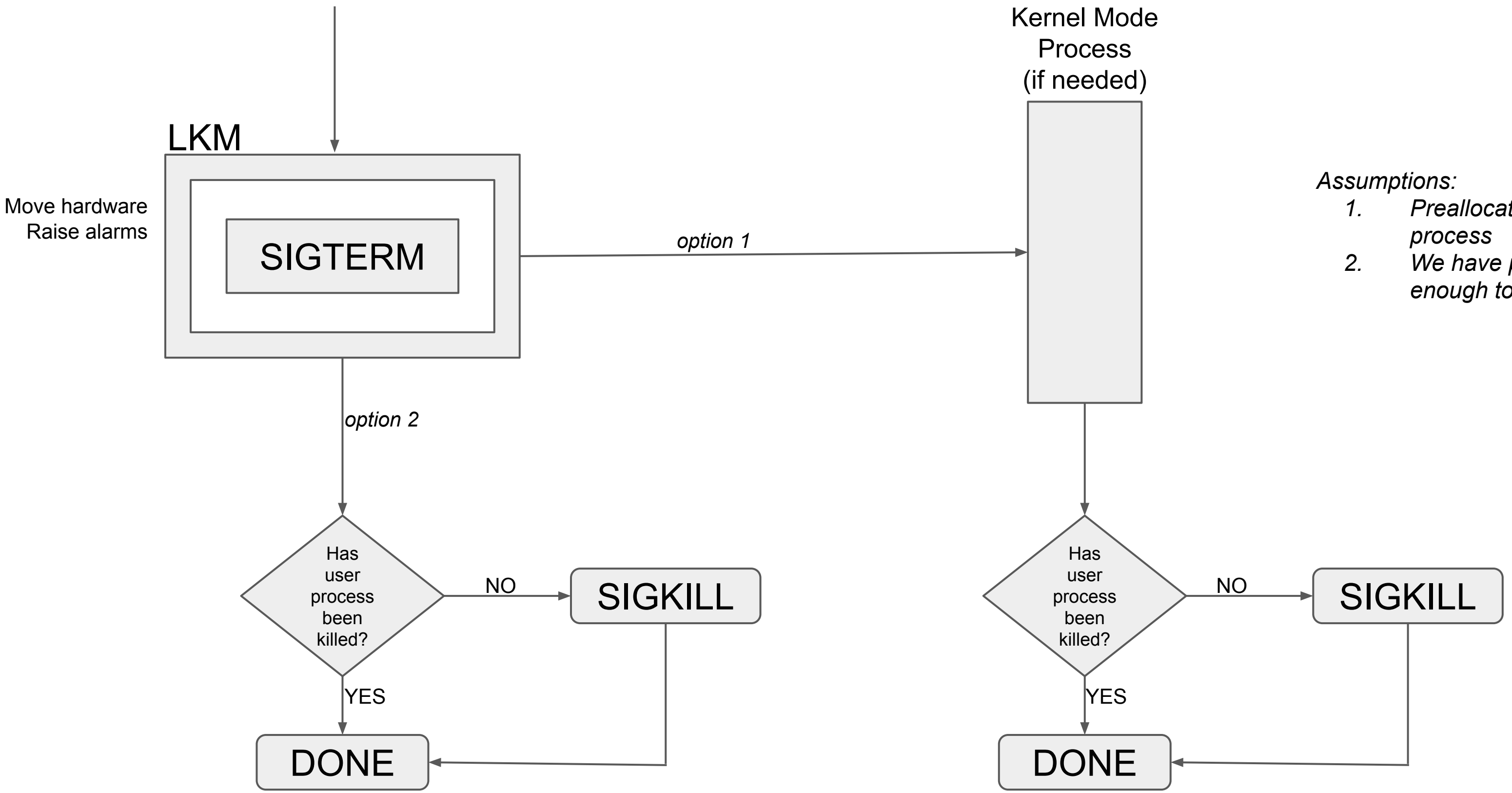
PRO

- Premarked as “unkillable”
- Access to kernel level and user space info

CON

- Slower to create / manage
- Likely slower than kernel execution

Graceful Shutdown - Potential Implementations



LKM
Move hardware
Raise alarms
SIGTERM
option 1
Kernel Mode Process (if needed)
option 2
Has user process been killed?
NO
SIGKILL
YES
DONE
Has user process been killed?
NO
SIGKILL
YES
DONE

Assumptions:

1. *Preallocate memory for process*
2. *We have pre-empted early enough to complete this*

Questions?