Configuring the Heap and Garbage Collector for Real-Time Programming.

. . . A user's perspective to garbage collection

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Structure

- What is the purpose of a garbage collector
- What knobs are there to turn?
- Different GCs: Blocking, Generational, Concurrent, Conservative, Mixed
- GCs that couple work with allocation
- Example
- Conclusion

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What is the purpose of GC?

An automatic mechanism for memory management, to take the burden of

- ➔ **memory reclamation**
- ➔ **memory defragmentation**
- ➔ **dangling references**
- ➔ **memory leaks / forgotten *free()*s**

from the user.

GC as a *black box*

The user does not understand what is happening inside the GC algorithm!

But: The user might configure the behaviour of the GC.

We have a black box with knobs to turn!

To be able to configure the GC seen as a black box, the user needs guidance and tools to make a good decision.

Else he will make bad decisions!

What are these knobs?

- Heap size (min/initial, max, ...)
- Object count
- Amount of GC work
  - GC priority
  - GC threshold
  - GC scanning rate
  - GC CPU-percentage
  - ...
- Control GC Algorithm
  - Select a GC implementation

In a blocking garbage collector

Effect of changing heap size h:

- GC pause time p changes, ex. $p \sim h$
- GC pause frequency f changes, ex. $f \sim 1/h$
- Application behaviour changes:
  - Runs fine for $h >= h_{min}$
  - crashes for $h < h_{min}$

What is the value of h_{min}?

In a generational GC

Effect of changing heap size h:

➔ **Same behaviour as blocking GC, but**

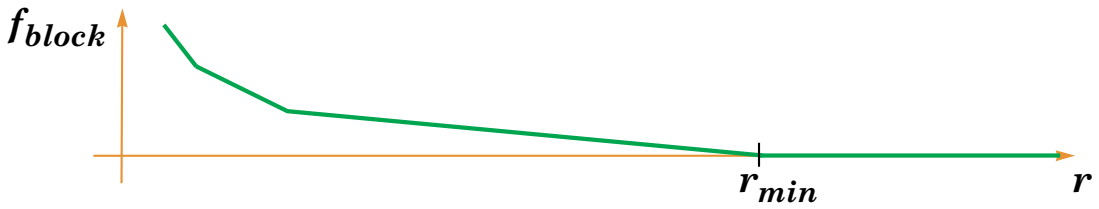
- **Shorter pause time p_{young} and higher frequency f_{young} for collecting young**
- **Pause time p_{old} for collecting old as long as for blocking GC.**
- **Application dependency: lower frequency f_{old} of collections of old area?**

Concurrent Garbage Collector

GC running e.g. as a separate thread.

Values to be adjusted

- ➔ **heap size h**
- ➔ **GC threshold t (when does GC start?)**
- ➔ **GC rate r / priority / etc.**



Minumum GC rate r_{min} depends on application. We need a tool to determine this value!

Conservative Garbage Collector

Change of configuration or of input data has unpredictable effects on GC performance and effectiveness!

⇒ **useless for nearly any serious application!**

Mixed approaches

Example: HotSpot offering choice between

- **Generational GC + Blocking for old area**

--or--

- **Generational GC + Incremental for old**

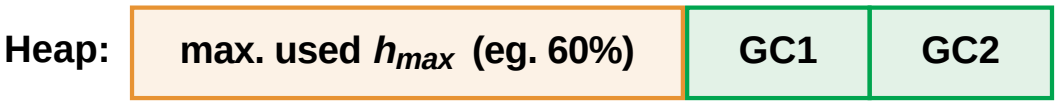
What guides the user by his choice?

If one choice does not work, just try the other one and hope?

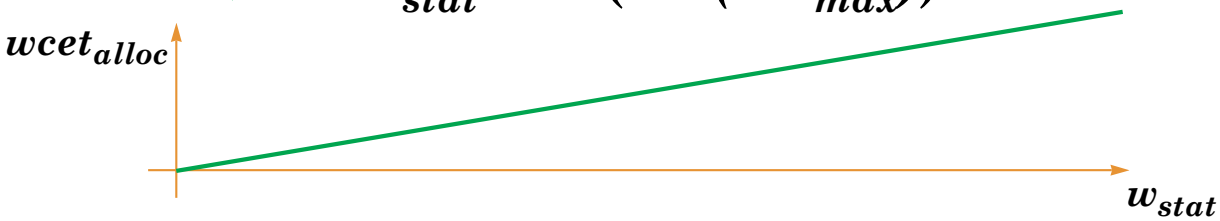
GC coupled with allocation

Values to be adjusted by user

- **heap size h**
- **static GC work w_{stat} on allocation**



$\Rightarrow$ **set w_{stat} to 5 (= $2/(1-h_{max})$)**



Requires tool to determine h_{max} and w_{stat}.

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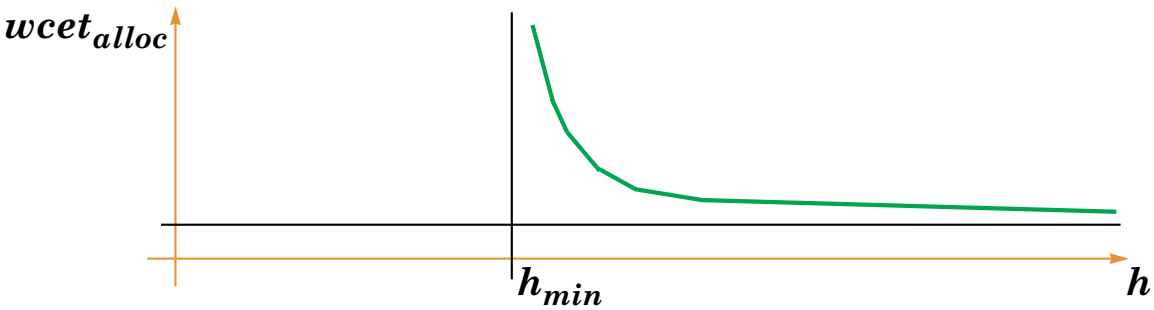
GC work determined dynamically

Values to be adjusted by user

- **heap size h**

GC determines w_{dyn} as function of amount of free memory.



Tool to select h and determine $wcet_{alloc}$ needed.

Example

```
public class HelloWorld {
  public static void main(String[] args) {
    int n,s,c;
    s = 0;
    c = 14;
    for(int i=0; i<30; i++) {
      String s1 = "              ".substring(s+14);
      String s2 = "              ".substring(s/2+7);
      System.out.println(s1+"Hello "+s2+"World!");
      s = s + c / 4;
      c = c - s / 4;
    }
  }
}
```


Example

```
> jamaica -analyse 5 HelloWorld
> HelloWorld
              Hello        World!
           Hello       World!
[...]
### Application used at most 117224 bytes for Java heap
###
###   heapSize    wcet dynamic    wcet static
###   337k                 7             3
###   226k                 7             4
###   189k                10             5
###   170k                14             6
###   162k                16             7
###   152k                21             8
###   143k                28            10
###   134k                40            14
###   121k               138            40
###   118k               286            80
```

Example

Determination of worst-case execution time of

```
new StringBuffer()
```

Determine number of blocks:

```
> numblocks java.lang.StringBuffer
1
```

Worst-case execution time:

$$wcet = numblocks \cdot max_{gc\_unit} \cdot wcet_{gc\_unit}$$

$$wcet_{152k} = 1 \cdot 21 \cdot 2\mu s = 42\mu s$$

$$wcet_{226k} = 1 \cdot 7 \cdot 2\mu s = 14\mu s$$

Comparison

GC Algorithm	Knobs	Effects on
Blocking	h	pause times p
Generational	h, ...	pause freq. f
Concurrent	h, r, ...	blocking freq. f GC overhead
Static on alloc	h, w_s	$wcet_{alloc}$
Dynamic on alloc	h	$wcet_{alloc}$

Conclusion

- **The user can not be burdened with understanding the GC mechanism used by an implementation.**
- **Current implementations lack tools that guide the user in making a good choice for GC configuration**
- **Fewer knobs are better! A value that can't be changed can't be set wrong.**