# DieHard:
# Probabilistic Memory Safety for Unsafe Programming Languages

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Presented by:

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    - (adj.) strongly or fanatically determined or devoted

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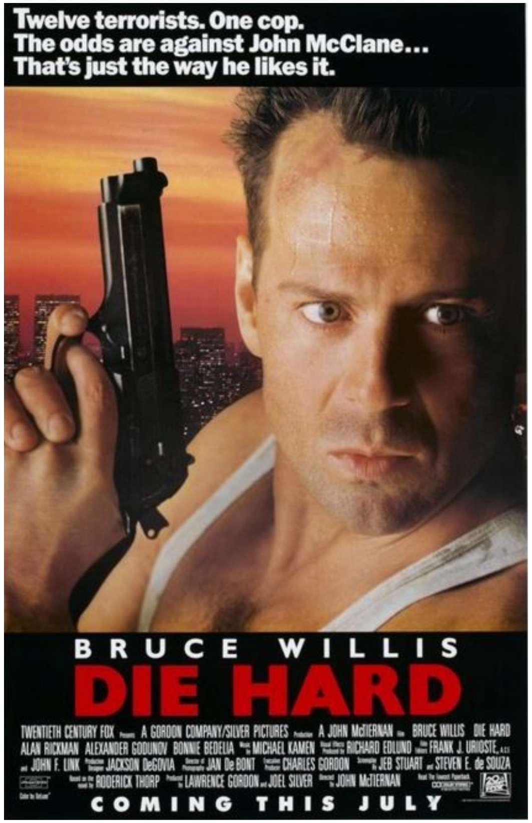

# *Frivolity*

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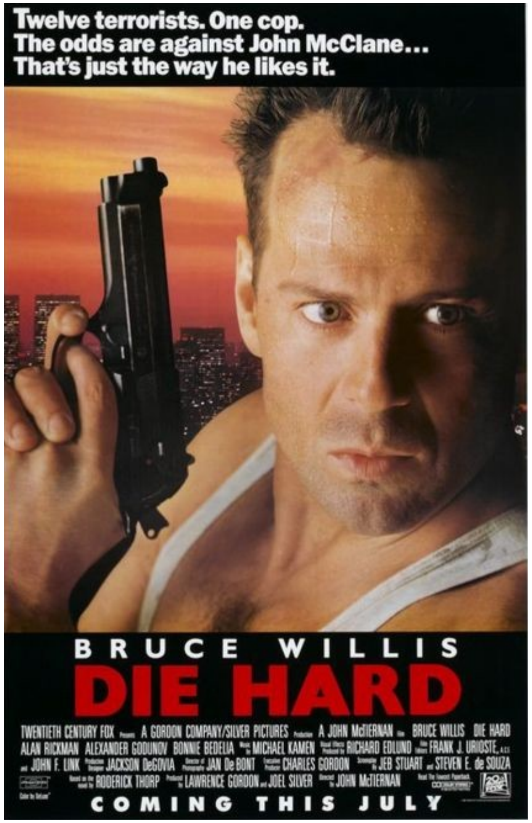


# *Problems with Unsafe Languages*

- C, C++: pervasive apps, but **memory unsafe**
- Numerous opportunities for security vulnerabilities, **errors**
  - Double **`free`**
  - Invalid **`free`**
  - Uninitialized reads
  - Dangling pointers
  - Buffer overflows (stack & **heap**)

# *Current Approaches*

- **Unsound, *may* work or abort**
  - Windows, GNU libc, etc., *Rx*
- **Unsound, *will definitely* continue**
  - *Failure oblivious* (Rinard) **
- **Sound, *definitely aborts* (fail-safe)**
  - *CCured*, *CRED*, *SAFECode*
    - Requires C source, programmer intervention
    - 30% to 20X slowdowns
  - Good for *debugging*, less for *deployment*

# *DieHard*

- **Sound execution (with high probability)**
- **Fully-randomized** memory manager
  - Increases odds of **benign** memory errors
  - Ensures different heaps across users
- **Replication**
  - Run multiple **replicas** simultaneously, vote on results
    - Detects crashing & non-crashing errors
- Trades space (and CPU?) for increased reliability

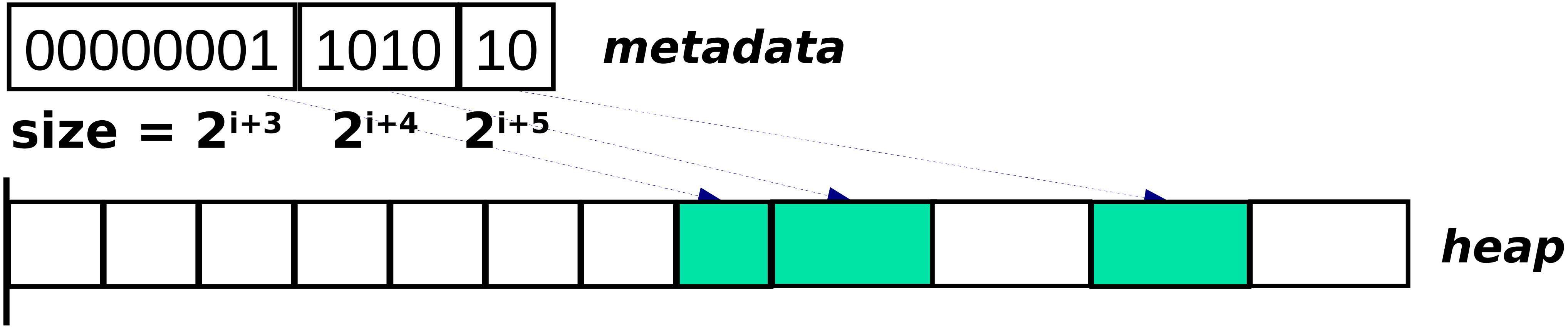
# *Soundness for “Erroneous” Programs*

- Consider **infinite-heap** allocator:
  - All **`new`**s *fresh*; ignore **`delete`**
    - No dangling pointers, invalid frees, double frees
  - Every object **infinitely large**
    - No buffer overflows, data overwrites
- Transparent to correct program
- “Erroneous” programs **sound**

# Approximating Infinite Heaps

- Infinite ⇒ M-heaps: probabilistic soundness
- **Option 1:** Pad allocations & defer deallocations
  - \+ Simple
  - – **No** protection from larger overflows
    - – pad = 8 bytes, overflow = 9 bytes…
  - – *Deterministic*: overflow crashes *everyone*
- **Better:** randomize heap
  - \+ Probabilistic protection against errors
    - \+ *Independent* across heaps
  - ? Efficient implementation…

# Randomized Heap Layout



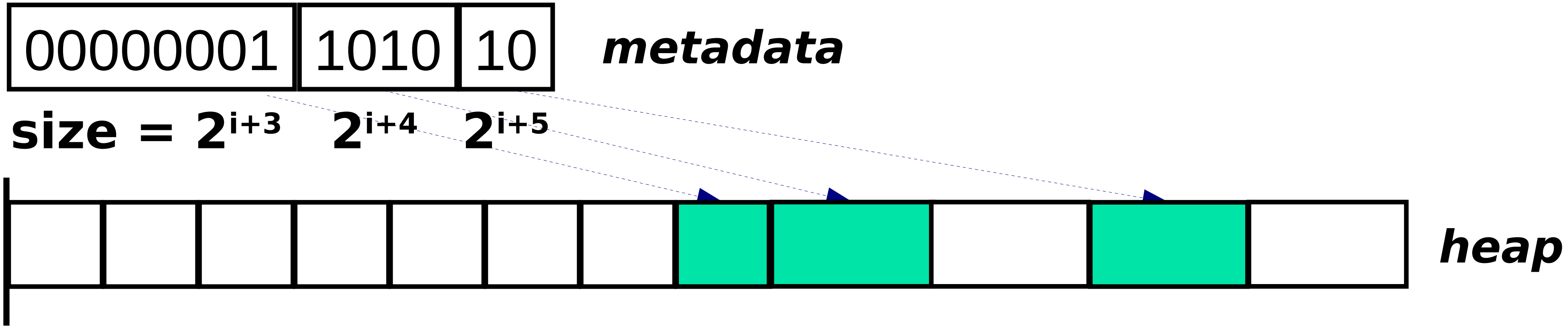
00000001 | 1010 | 10 **_metadata_**

**size = $2^{i+3}$ $2^{i+4}$ $2^{i+5}$**

**_heap_**

- Bitmap-based, **segregated** size classes
  - Bit represents one **object** of given size
    - i.e., one bit = $2^{i+3}$ bytes, etc.
  - Prevents fragmentation

# *Randomized Allocation*



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**`malloc(sz):`**

  - `compute size class = ceil(log₂ sz) – 3`
  - **randomly** probe bitmap for zero-bit (free)
- Fast: runtime O(1)
  - $M=2 \Rightarrow E[\#\text{ of probes}] \leq 2$

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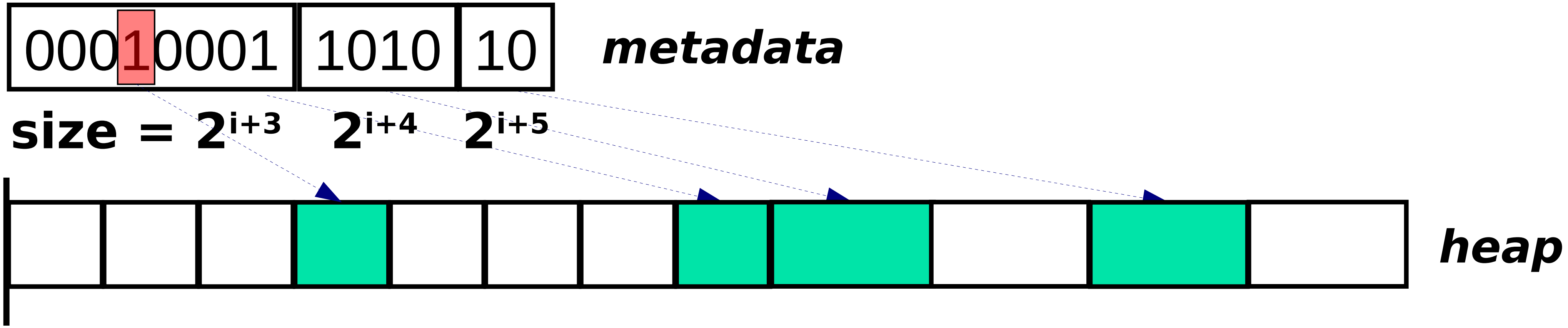

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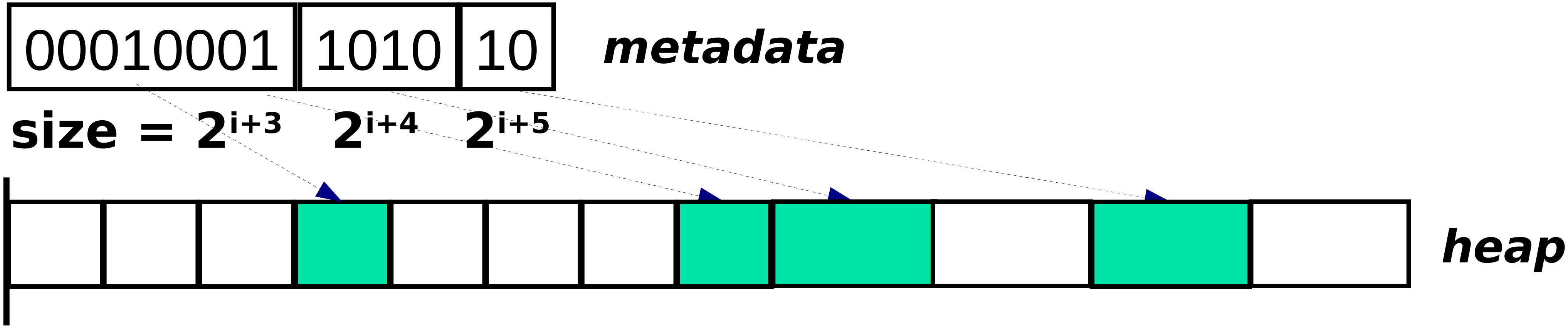

`free(ptr):`

- Ensure object valid (aligned)
- Check bitmap
- Reset bit

- Prevents invalid frees, double frees

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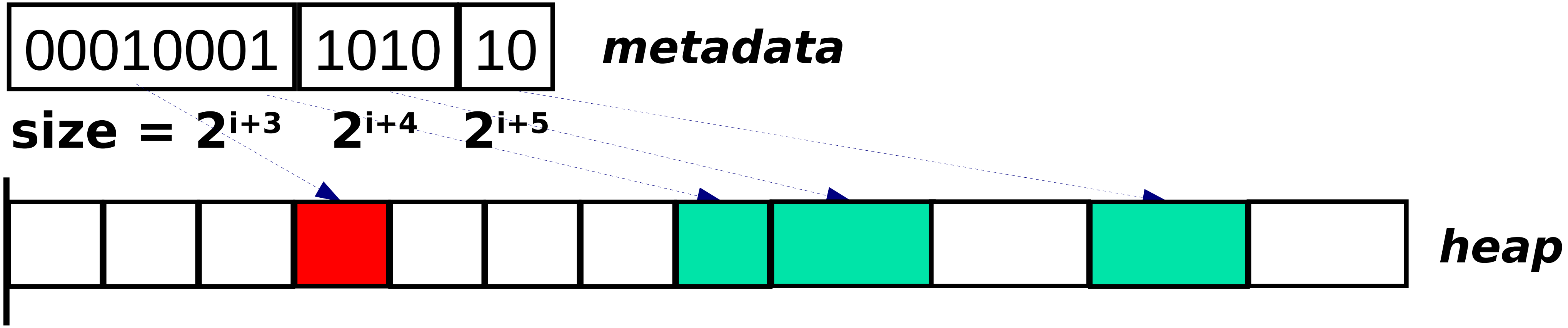

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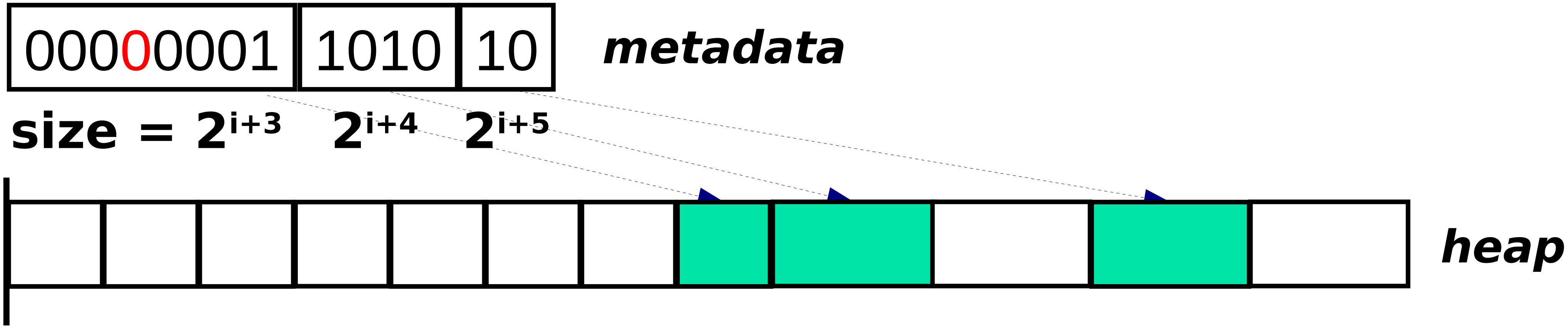

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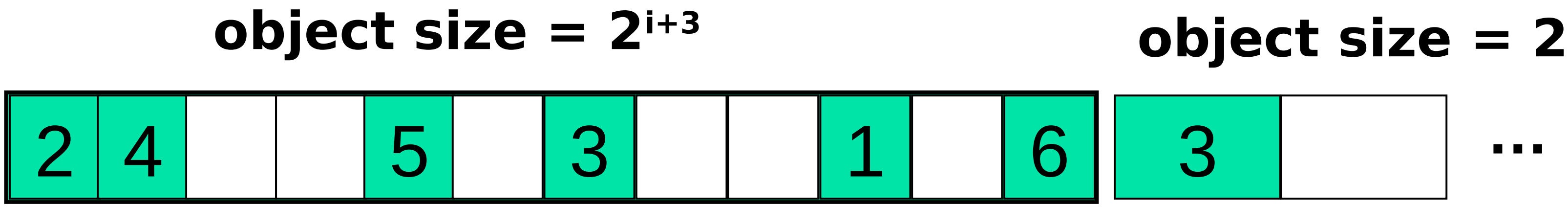
# *Randomized Heaps & Reliability*



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- Different run = different heap
  - Errors across heaps independent

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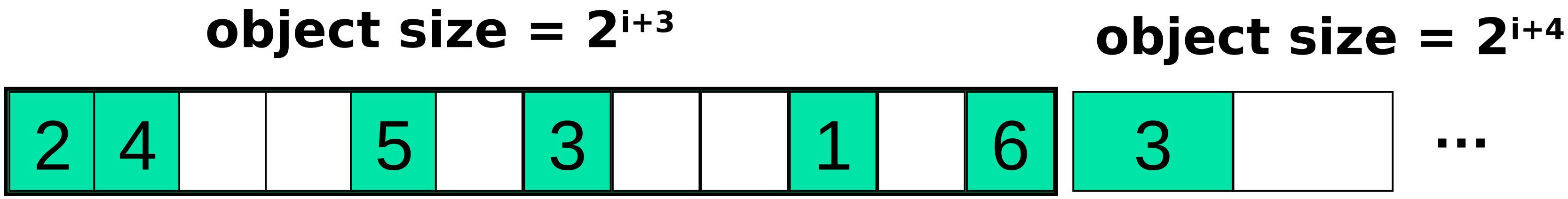

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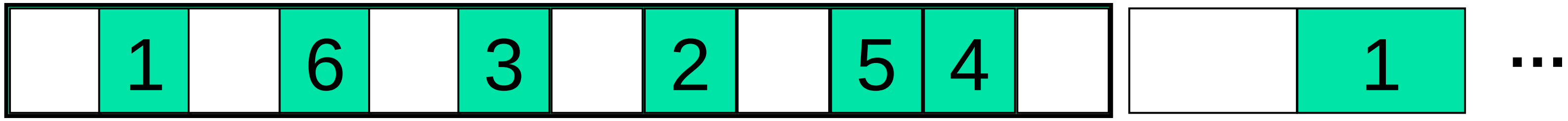

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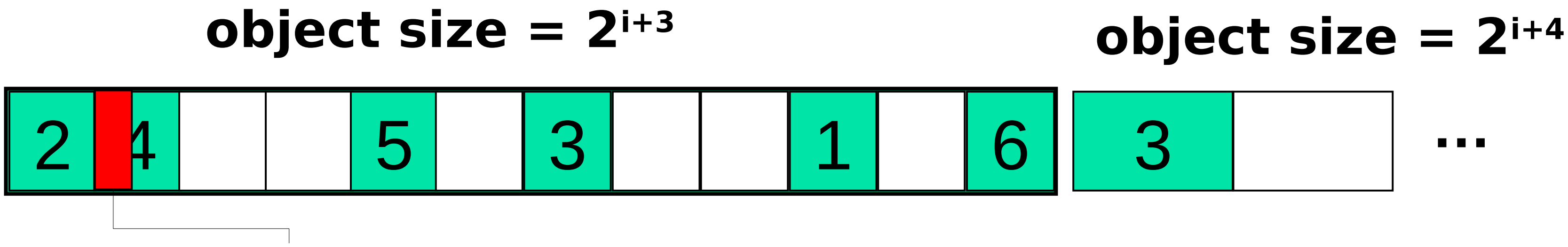

*My Mozilla: “malignant” overflow*

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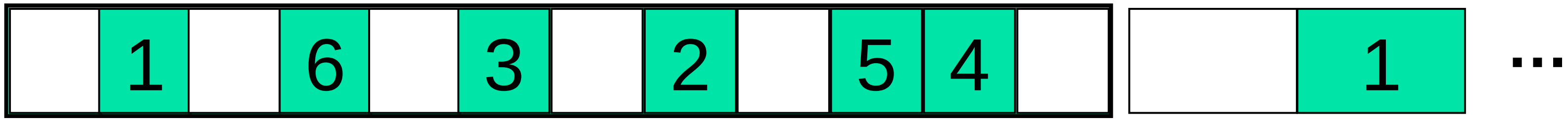

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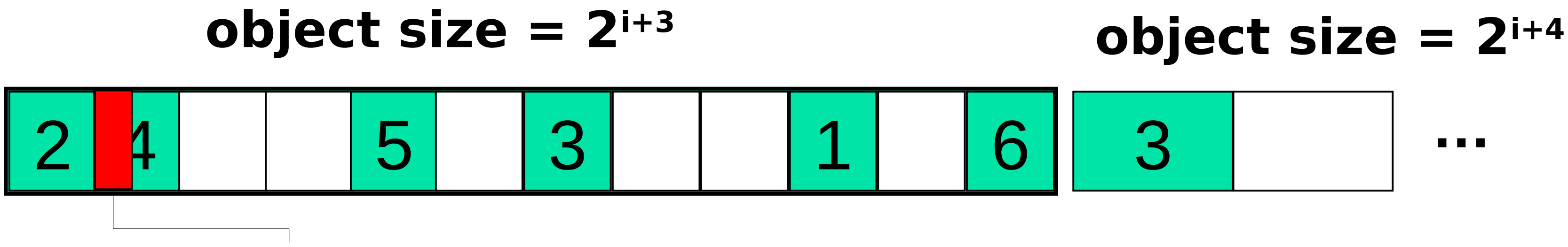

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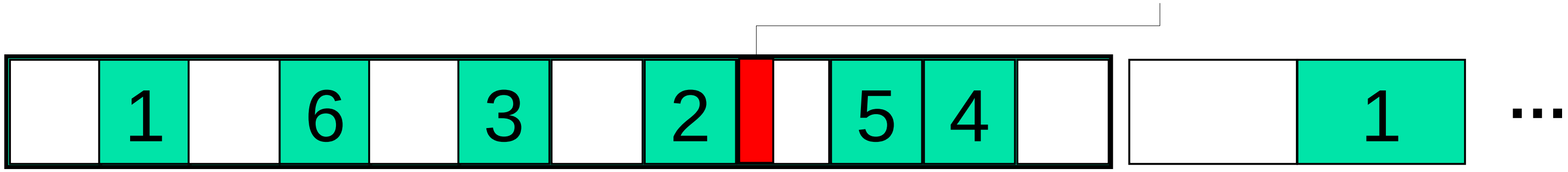
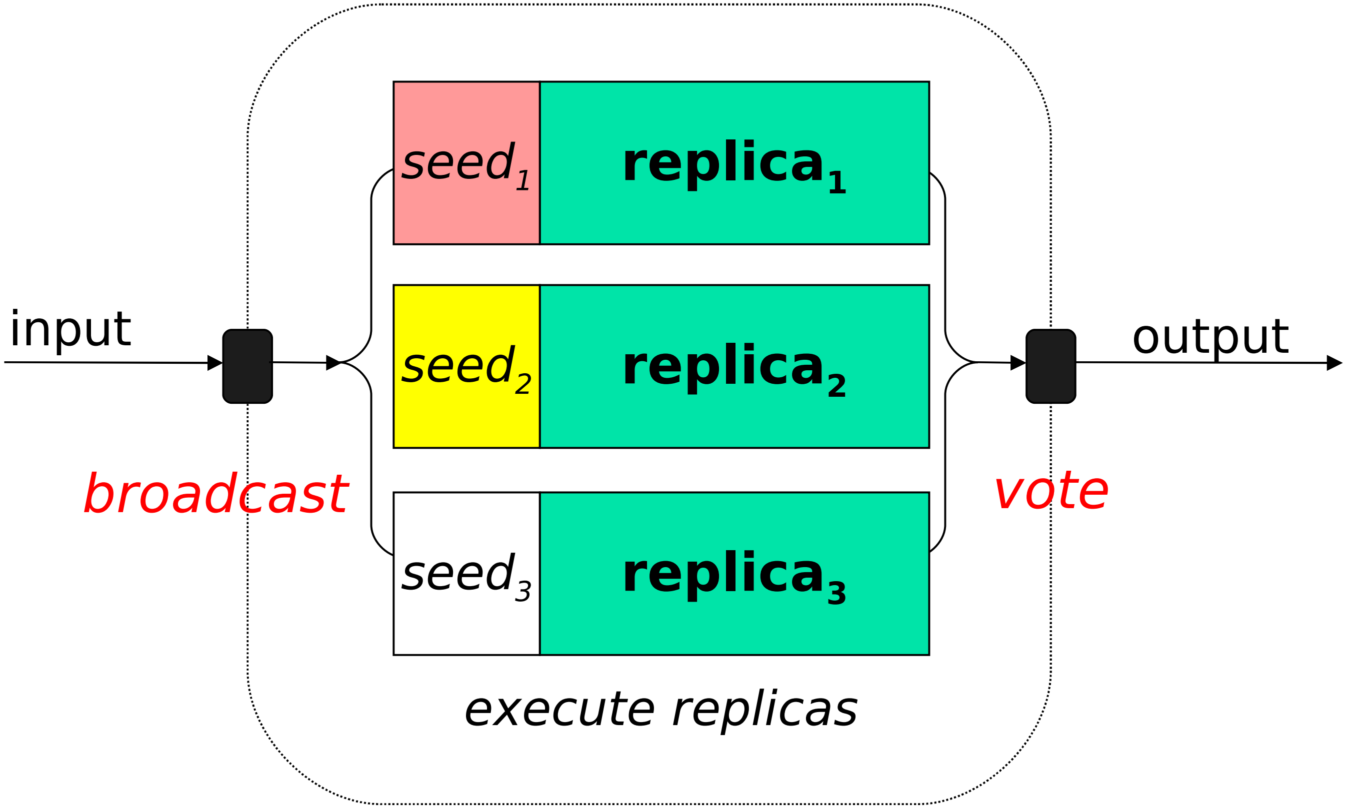
*Your Mozilla: “benign” overflow*



# DieHard software architecture



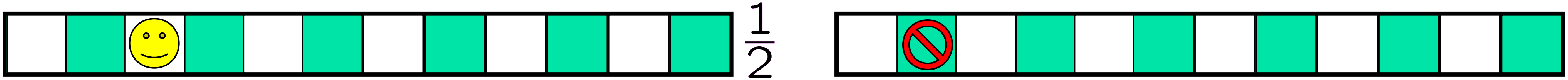
- Each replica has different allocator
- “Output equivalent” – kill failed replicas

# Results

- Analytical results
  - Buffer overflows
  - Dangling pointer errors
  - Uninitialized reads
- Empirical results
  - Runtime overhead
  - Error avoidance
    - Injected faults & actual applications

# Analytical Results: Buffer Overflows

- Model overflow as write of live data
    - Heap half full (max occupancy)



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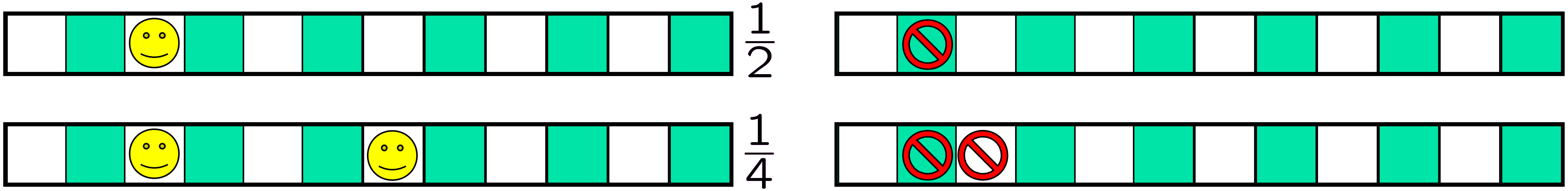

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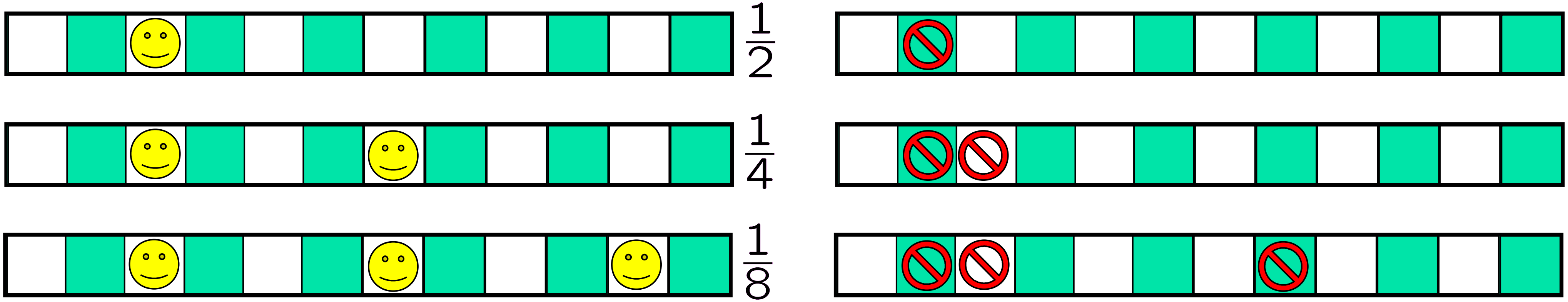
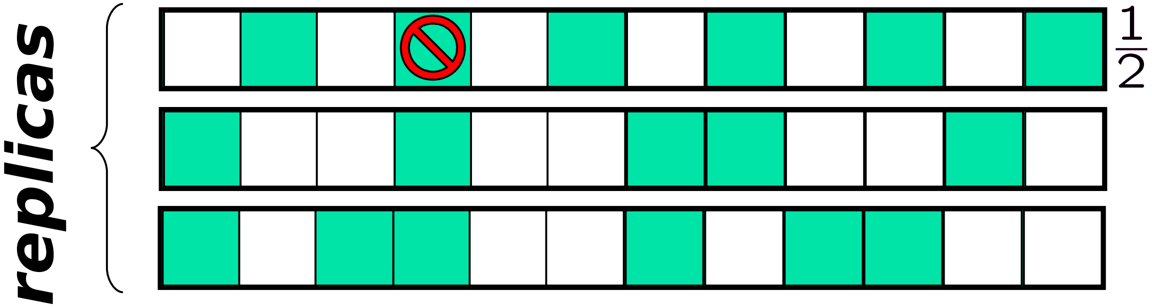


$$\mathrm{P(No\ Overflow)} \geq \left(\frac{1}{2}\right)^{N}$$

# Analytical Results: Buffer Overflows

- **Replicas:** Increase odds of avoiding overflow in *at least one* replica



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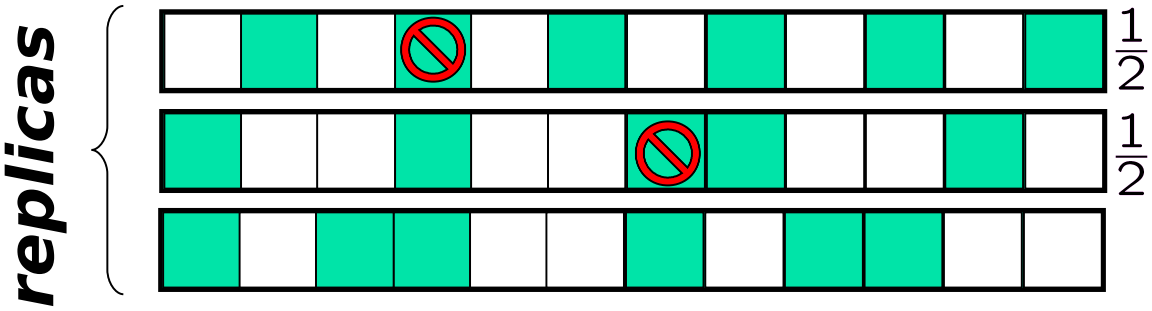

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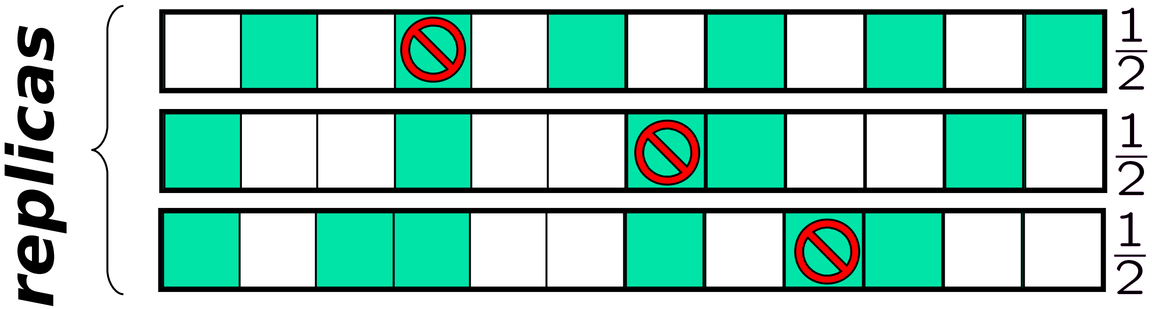
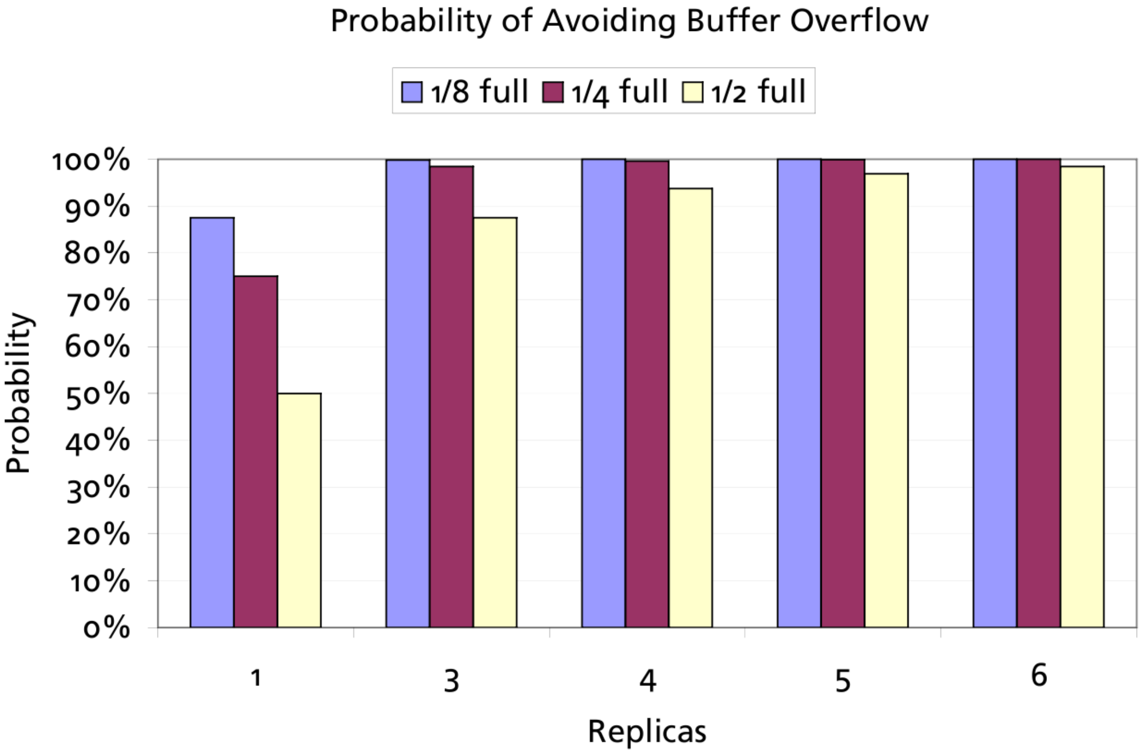


- P(Overflow in **all** replicas) = $(1/2)^3 = 1/8$
- P(No overflow in $\geq$ 1 replica) = $1-(1/2)^3 = 7/8$

# Analytical Results: Buffer Overflows

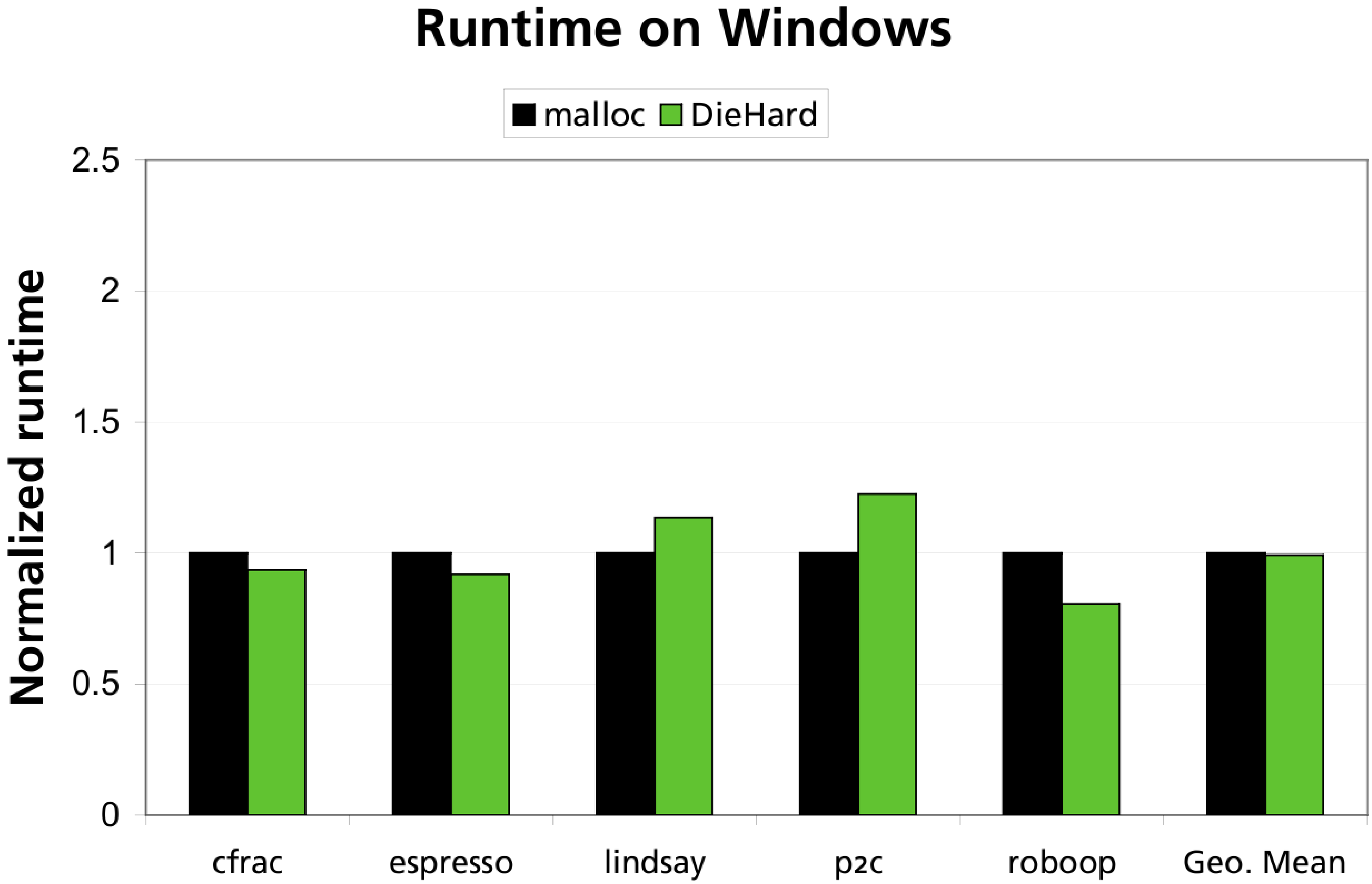
$$\text{P(No Overflow Error)} = 1 - \left[1 - \left(\frac{F}{H}\right)^N\right]^k$$

- *F* = free space
- *H* = heap size
- *N* = # objects worth of overflow
- *k* = replicas



- *Overflow one object*

# Empirical Results: Runtime



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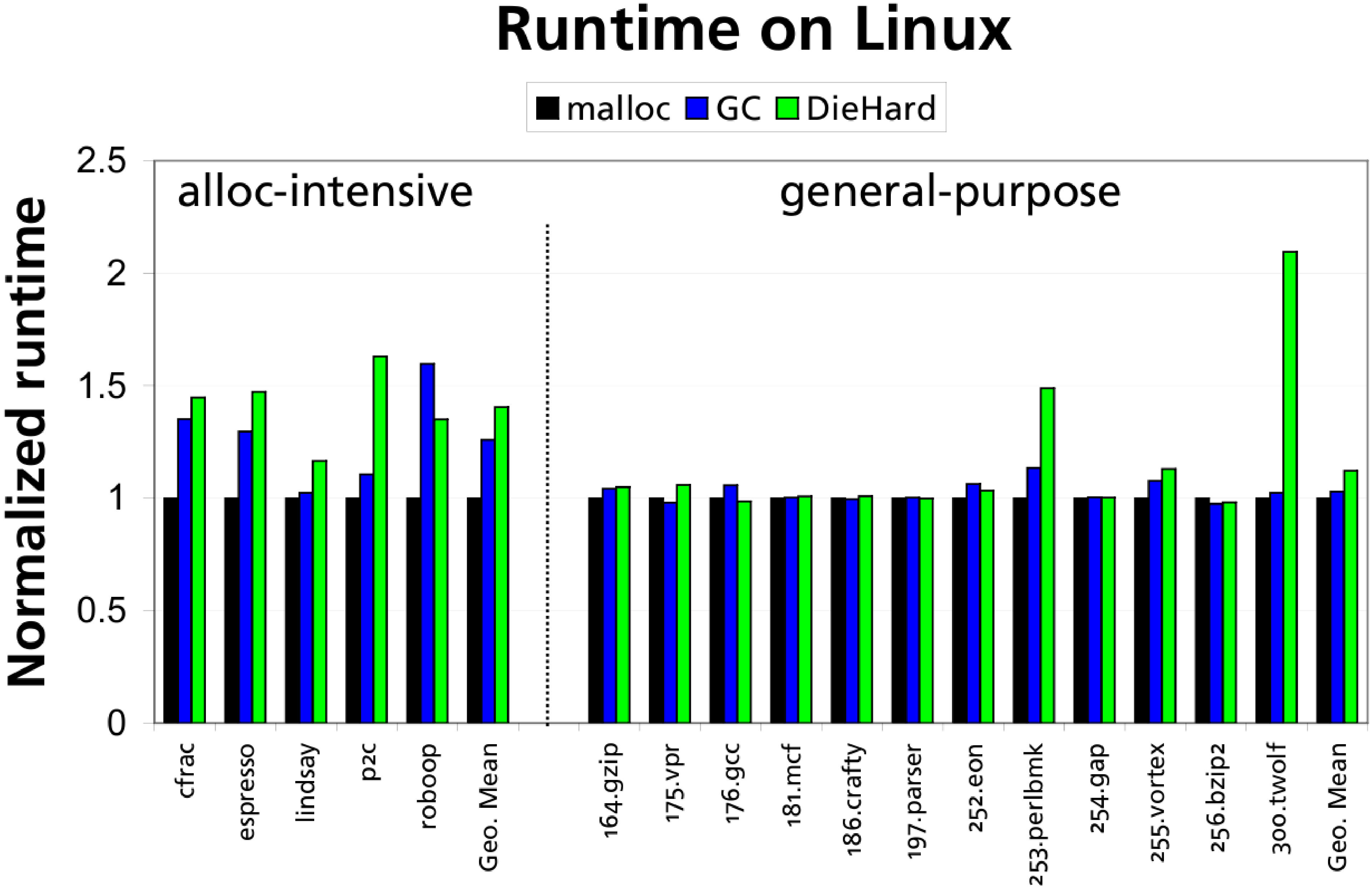

# Empirical Results: Error Avoidance

- **Injected faults:**
  - Dangling pointers (@50%, 10 allocations)
    - **glibc**: *crashes*; **DieHard**: *9/10 correct*
  - Overflows (@1%, 4 bytes over)
    - **glibc**: *crashes 9/10, inf loop*; **DieHard**: *10/10 correct*
- **Real faults:**
  - Avoids Squid web cache overflow
    - *Crashes BDW & glibc*
  - Avoids dangling pointer error in Mozilla
    - *DoS in glibc & Windows*

# *Conclusion*

- **Randomization + replicas = probabilistic memory safety**
  - Useful point between absolute soundness (fail-stop) and unsound
- **Trades hardware resources (RAM, CPU) for reliability**
  - Hardware trends
    - Larger memories, multi-core CPUs
  - Follows in footsteps of ECC memory, RAID

# *Major Weakness*

- Excessive memory, CPU usage
- **Fallacy:** we can forfeit extra memory and CPU resources because they are becoming cheaper
- For production use (seriously?)

- Inconsistent comparisons

# Related Work

- **Unsound, *will definitely* continue**
  - *Failure oblivious* (Rinald) [30, 32] **
    - Introduced idea of “boundless memory blocks”
    - Same benefits with less memory?
- DieHarder