Netherlands Forensic Institute
Ministry of Justice

Pre-boot RAM acquisition and compression

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Why memory forensics?

- What was the user doing?
- What applications were running?
- Is the system infected with malware?

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- **Cryptokeys!**

(Cold) boot attack

- Demonstrated in 2008 by Halderman *et al.*
  - "Lest We Remember: Cold Boot Attacks on Encryption Keys"

(Cold) boot attack

- msramdmp
- {bios, efi}_memimage
- Boot minimal OS?

Open challenges

- What if we want to acquire evidence from:
  - Many systems?
  - Both memory **and** disk?
  - Over the network?
  - Systems with 4G+ RAM?

Related work

- Bootable Linux CD / PXE for remote acquisition of multiple computers. (Cortjens 2014)

- Remote data acquisition on block devices in large environments. (van den Haak 2014)

Research question

“Is pre-boot compression a useful technique to reduce the destruction of data when an operating system is loaded?”

Goals

- Overwrite as little as possible
- Support >4G
- PXE & USB
- In a reasonable timeframe

Proposed solution

- Compress RAM content before starting OS
- Start Linux based OS
- Extract compressed data from RAM

Steps

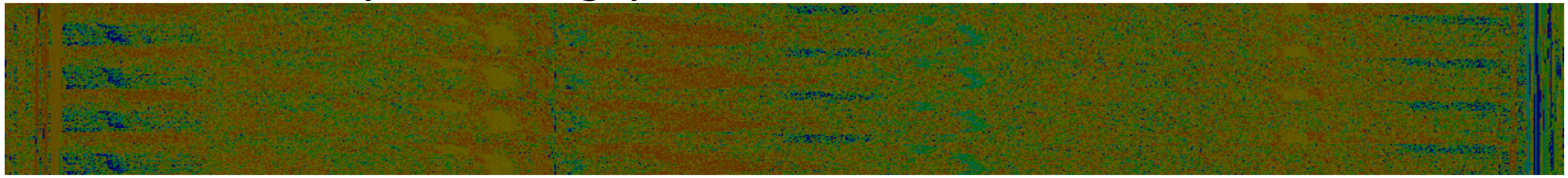
- Analysis of RAM content (Shannon Entropy)
- Selection of data compression algorithm
- Development of acquisition algorithm
- Development of Proof of Concept

RAM entropy

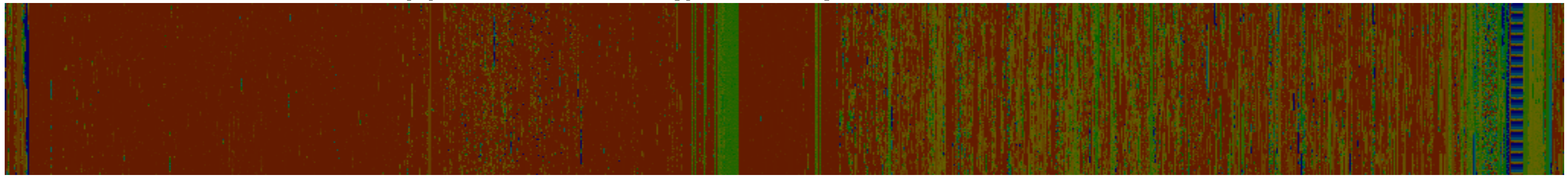
- 12 Dump from VMs
  - 256 MiB – 8 GiB
  - Windows & Linux
  - Several roles (desktop, server, live CD)
- Shannon Entropy (*H*)
  - In bits / byte of data
- Measured over whole RAM and in blocks
  - 4 & 16 kilobyte
- Average *H* 5.36 (σ 1.46)

RAM entropy

Windows 7 x86 (Office usage)



Tails 1.4 with encrypted folder (photos)



Data compression algorithms

- Tested 13 algorithms
  - Some with multiple presets
  - 19 tests in total

- Focused on memory usage
  - Every byte used is written over original data
  - Measured using Valgrind with Massif

- But also duration, compression factor, theoretical worst-case scenario…
  - Tested against the RAM dumps of prev. step

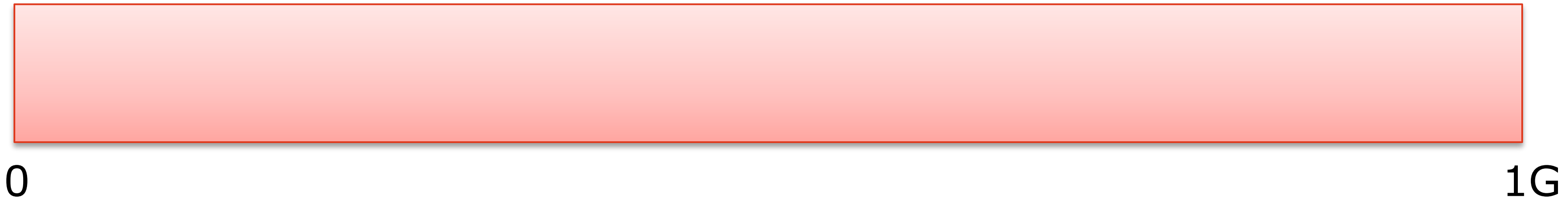
Data compression algorithms

- Selected LZW for Proof of Concept
  - 3,6 seconds / GiB (compression)
  - 60% avg. space saved
  - 7.7k mem usage (4.5k code, 3.2k stack, 0 heap)
  - Worst case output up to 104% of input length

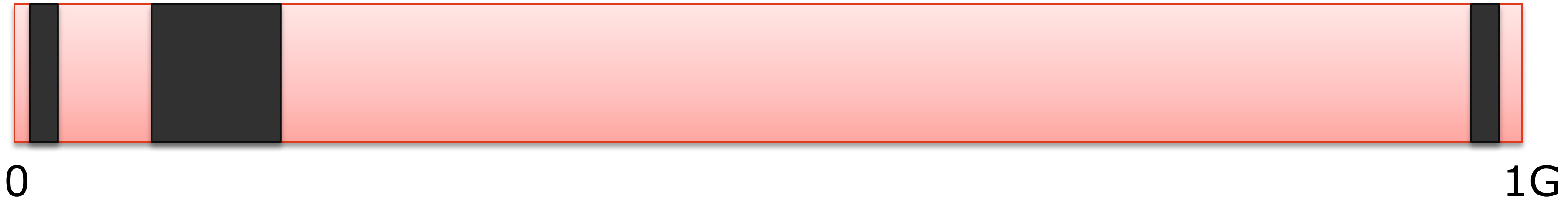
Acquisition algorithm

- Work in non-contiguous address space
- Don’t destroy more than absolutely necessary
- Make enough space to boot OS
- Protect compressed data from OS
- Provable forensic integrity

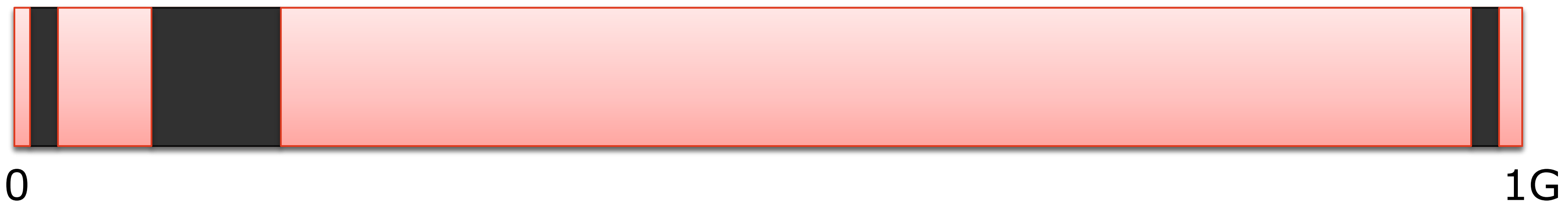
Acquisition algorithm



Acquisition algorithm



Acquisition algorithm



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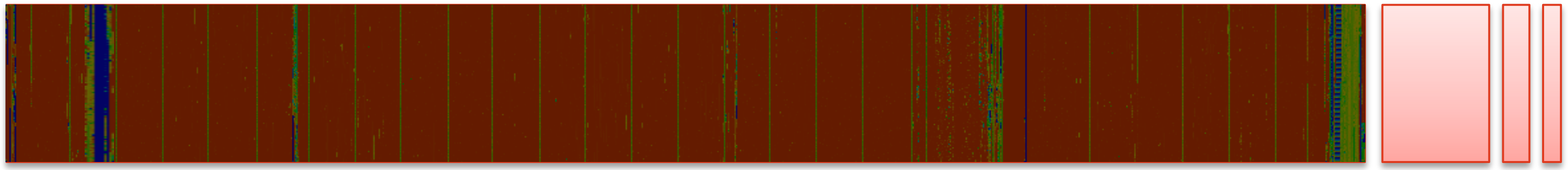

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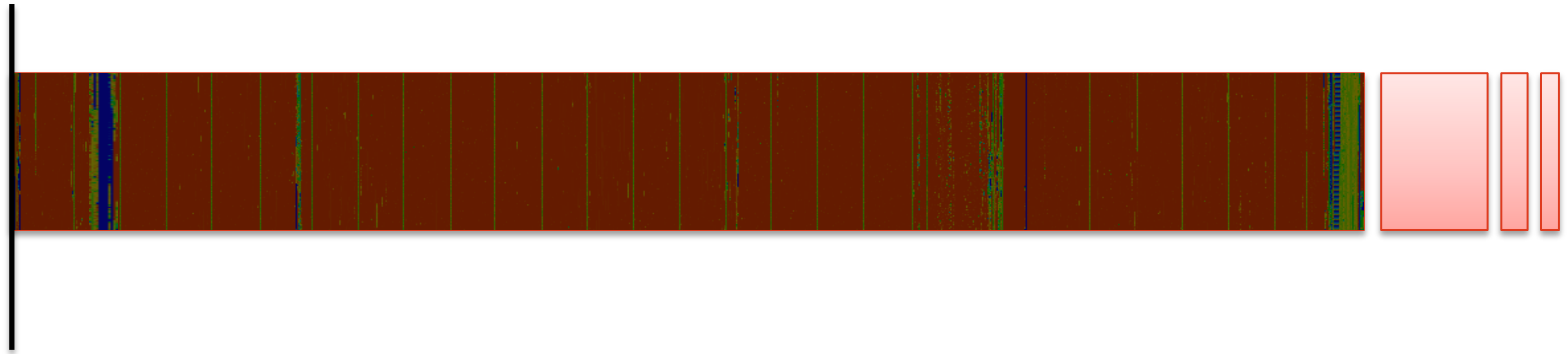

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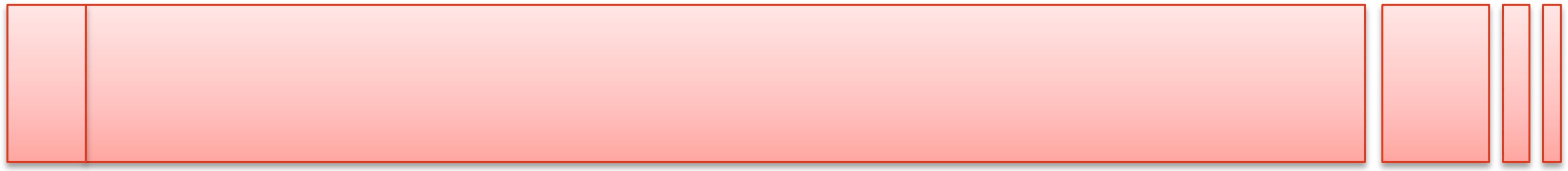

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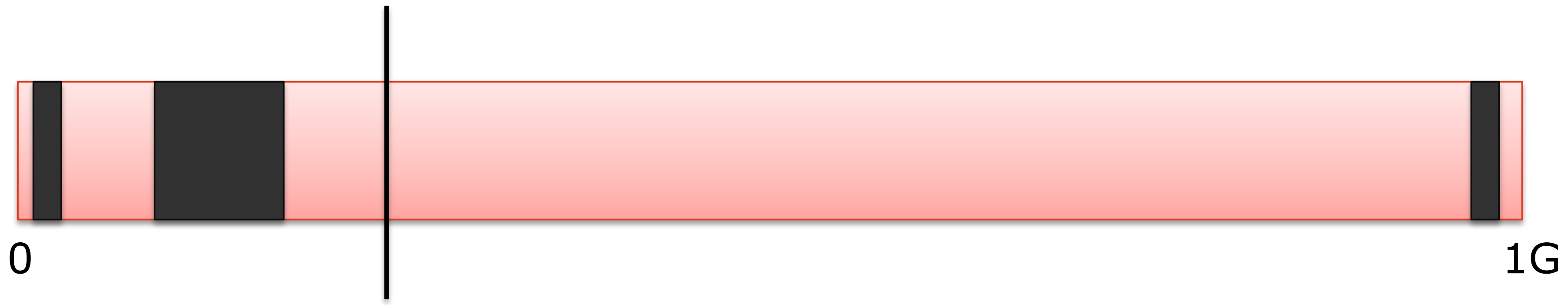

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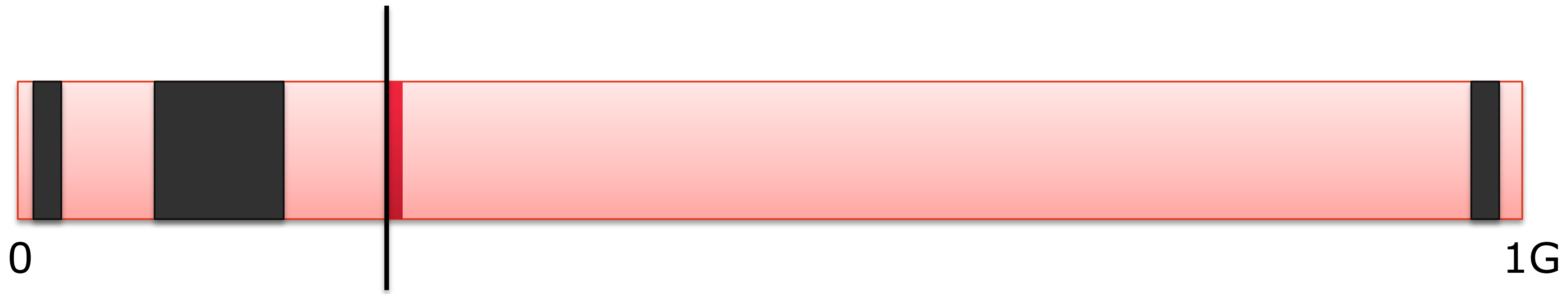

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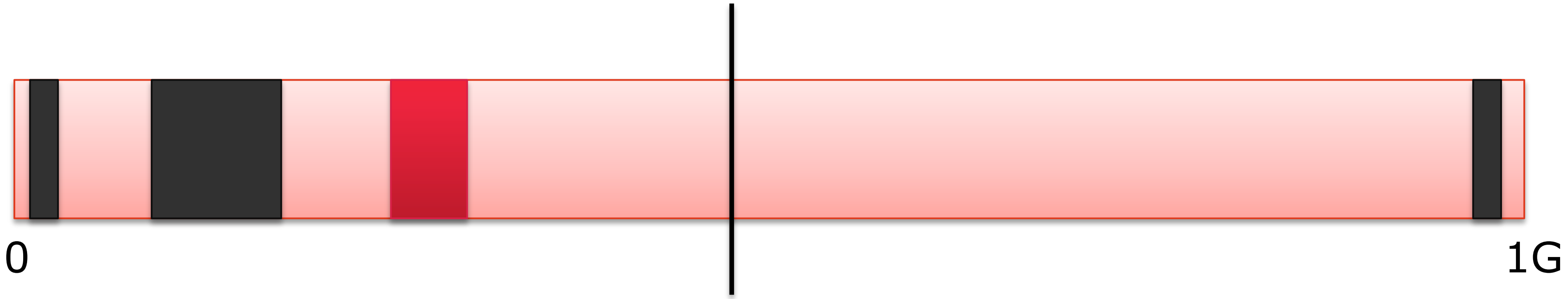

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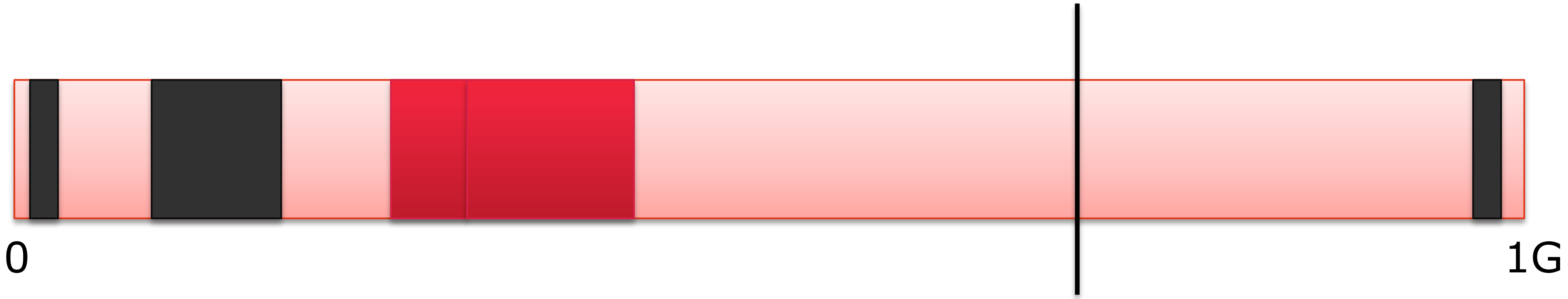

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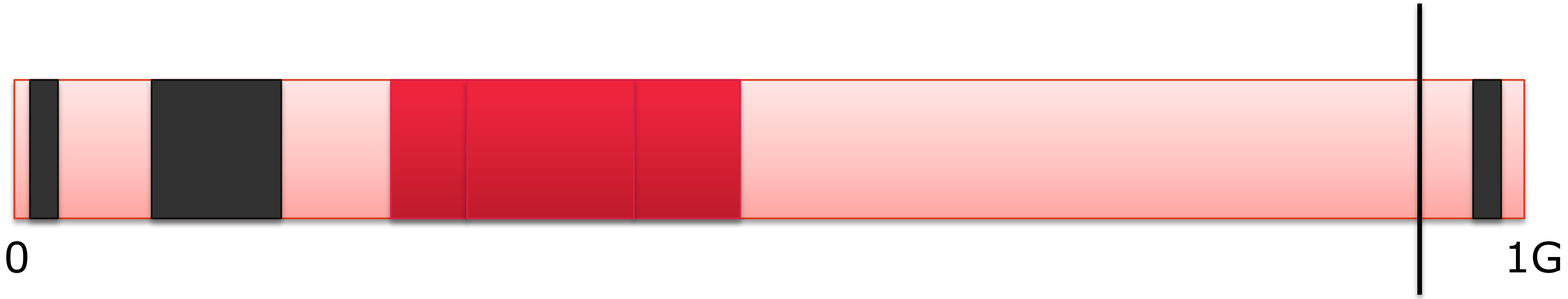

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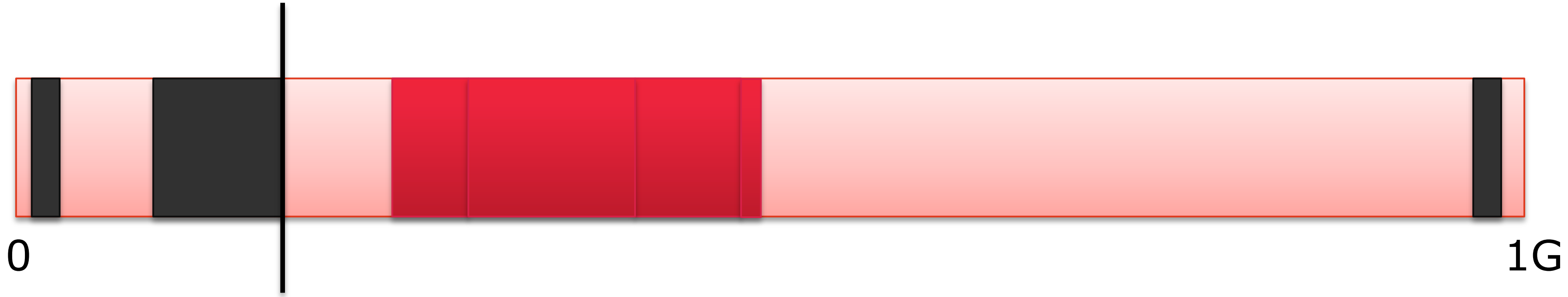

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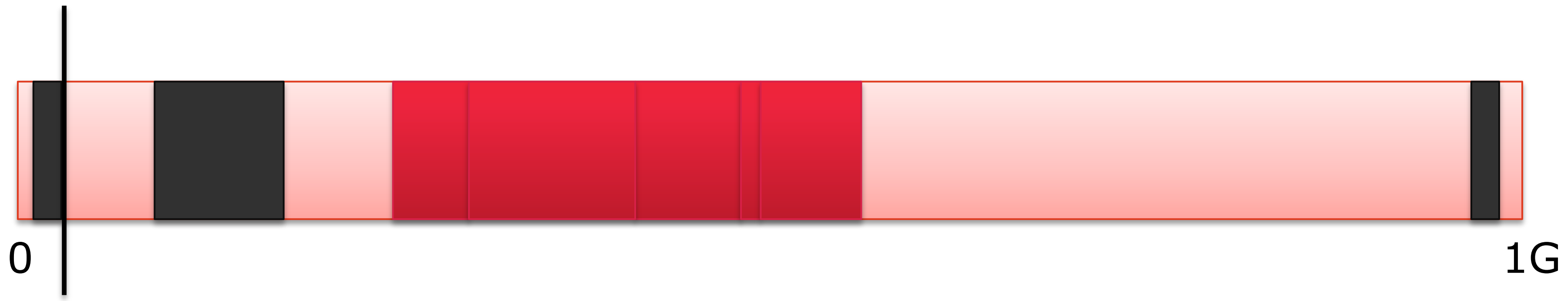

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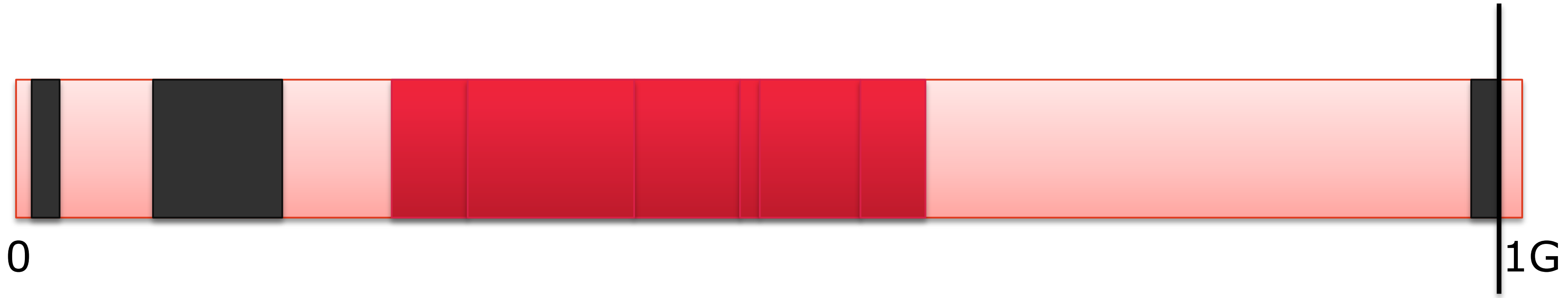

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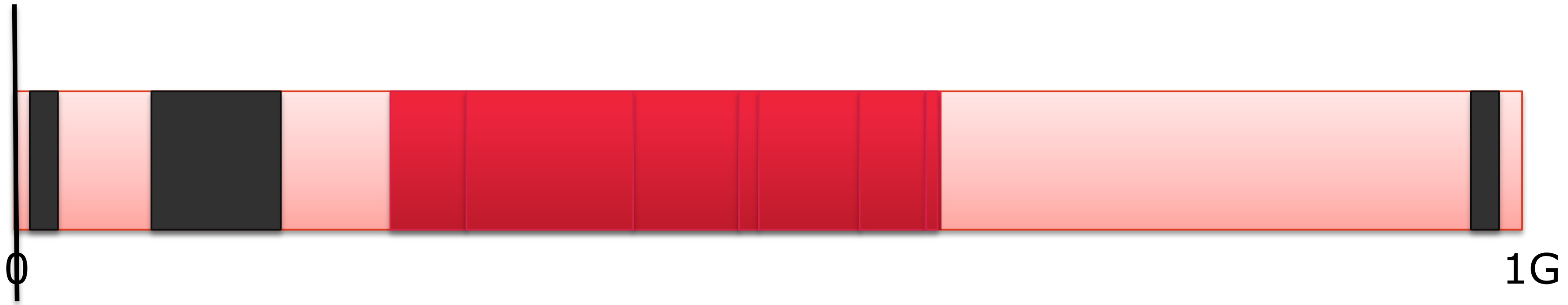

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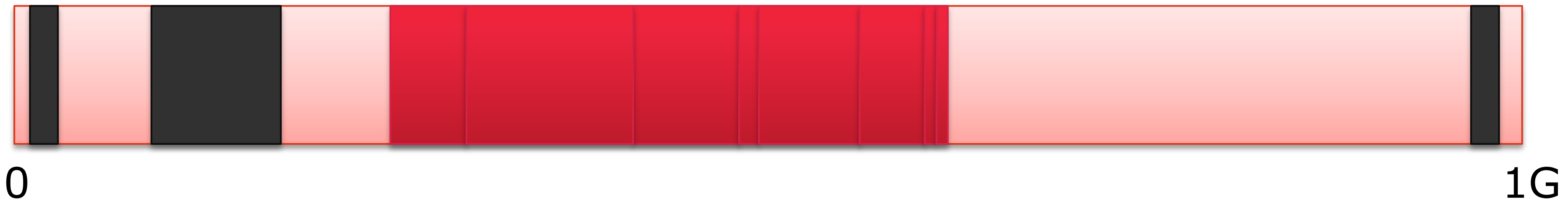

Proof of Concept

- Syslinux module to compress RAM
  - Supports CD, USB stick, PXE on BIOS & UEFI
  - Compress 100 MiB / block
  - SHA256 checksum over input
  - Modifies firmware memory map to hide compressed data
- OpenWRT based OS
  - Very small & low memory footprint
  - PXE boot needs 82 MiB free memory incl. ram disk
- Python script to extract compressed data
  - Patched /dev/mem interface

Proof of Concept

- Tested with USB & PXE
- Store compressed data to NFS volume
- Decompress on different machine
  - In worst-case ~20 MiB free memory available
- Modified QEMU to fill memory with pattern

Proof of Concept

```
$ ./decompress.py dumps/03a78c78-dd57-436f-b81e-5e66d8e3dc49
…
Memory map:

[               0] - [           9F7FF] OK
[           9F800] - [           FFFFF] MISSING
[          100000] - [          FFFFFF] OK
[         1000000] - [         73FFFFF] Checksum INVALID!
[         7400000] - [         D7FFFFF] OK
[         D800000] - [        13BFFFFF] OK
[        13C00000] - [        19FFFFFF] OK
[        1A000000] - [        1FEEFFFF] OK
[        1FEF0000] - [        1FEFEFFF] OK
[        1FEFF000] - [        1FEFFFFF] OK
```

Comparison with existing solutions

Method	Recovered		Not recoverable	
msramdmp	1022.8 M	99.883%	1.2 M	0.117%
bios_memimage	1022.7 M	99.872%	1.3 M	0.128%
Proof of Concept	1019.5 M	99.556%	4.5 M	0.444%
OpenWRT (ref)	878.0 M	85.700%	146.0 M	14.3%

Conclusion

- Concept works

- Slightly increased memory usage
  - But can also be used for other evidence gathering
  - Mostly accountable to Syslinux

Future work

- Test with UEFI based systems

- Modify Syslinux
  - 64-bit or PAE support
  - Lower memory usage?

- Test more scenario’s with low amount of RAM

- More samples to predict likelihood of success

QUESTIONS?

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