

## Belady's Anomaly with Round Robin

|      |   |   |   |   |   |   |   |   |   |    |    |    |
|------|---|---|---|---|---|---|---|---|---|----|----|----|
| Num  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Refs | a | b | c | d | a | b | e | a | b | c  | d  | e  |

|         |  |  |  |  |  |  |  |  |  |  |  |  |
|---------|--|--|--|--|--|--|--|--|--|--|--|--|
| Frame 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| Frame 2 |  |  |  |  |  |  |  |  |  |  |  |  |
| Frame 3 |  |  |  |  |  |  |  |  |  |  |  |  |

|      |   |   |   |   |   |   |   |   |   |    |    |    |
|------|---|---|---|---|---|---|---|---|---|----|----|----|
| Num  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Refs | a | b | c | d | a | b | e | a | b | c  | d  | e  |

|         |  |  |  |  |  |  |  |  |  |  |  |  |
|---------|--|--|--|--|--|--|--|--|--|--|--|--|
| Frame 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| Frame 2 |  |  |  |  |  |  |  |  |  |  |  |  |
| Frame 3 |  |  |  |  |  |  |  |  |  |  |  |  |
| Frame 4 |  |  |  |  |  |  |  |  |  |  |  |  |

## Belady's Anomaly with Round Robin (filled)

|         |          |          |          |          |          |          |          |          |          |          |          |          |
|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Num     | 1        | 2        | 3        | 4        | 5        | 6        | 7        | 8        | 9        | 10       | 11       | 12       |
| Refs    | a        | b        | c        | d        | a        | b        | e        | a        | b        | c        | d        | e        |
| Frame 1 | <b>a</b> | a        | a        | <b>d</b> | d        | d        | <b>e</b> | e        | e        | e        | e        | <i>e</i> |
| Frame 2 |          | <b>b</b> | b        | b        | <b>a</b> | a        | a        | <i>a</i> | a        | <b>c</b> | c        | c        |
| Frame 3 |          |          | <b>c</b> | c        | c        | <b>b</b> | b        | b        | <i>b</i> | b        | <b>d</b> | d        |

|         |          |          |          |          |          |          |          |          |          |          |          |          |
|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Num     | 1        | 2        | 3        | 4        | 5        | 6        | 7        | 8        | 9        | 10       | 11       | 12       |
| Refs    | a        | b        | c        | d        | a        | b        | e        | a        | b        | c        | d        | e        |
| Frame 1 | <b>a</b> | a        | a        | a        | <i>a</i> | a        | <b>e</b> | e        | e        | e        | <b>d</b> | d        |
| Frame 2 |          | <b>b</b> | b        | b        | b        | <i>b</i> | b        | <b>a</b> | a        | a        | a        | <b>e</b> |
| Frame 3 |          |          | <b>c</b> | c        | c        | c        | c        | c        | <b>b</b> | b        | b        | b        |
| Frame 4 |          |          |          | <b>d</b> | d        | d        | d        | d        | d        | <b>c</b> | c        | c        |

## No Belady's Anomaly with LRU

|         |   |   |   |   |   |   |   |   |   |    |    |    |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|
| Num     | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Refs    | a | b | c | d | a | b | e | a | b | c  | d  | e  |
| Frame 1 |   |   |   |   |   |   |   |   |   |    |    |    |
| Frame 2 |   |   |   |   |   |   |   |   |   |    |    |    |
| Frame 3 |   |   |   |   |   |   |   |   |   |    |    |    |

|         |   |   |   |   |   |   |   |   |   |    |    |    |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|
| Num     | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Refs    | a | b | c | d | a | b | e | a | b | c  | d  | e  |
| Frame 1 |   |   |   |   |   |   |   |   |   |    |    |    |
| Frame 2 |   |   |   |   |   |   |   |   |   |    |    |    |
| Frame 3 |   |   |   |   |   |   |   |   |   |    |    |    |
| Frame 4 |   |   |   |   |   |   |   |   |   |    |    |    |

## No Belady's Anomaly with LRU (filled)

|         |          |          |          |          |          |          |          |          |          |          |          |          |
|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Num     | 1        | 2        | 3        | 4        | 5        | 6        | 7        | 8        | 9        | 10       | 11       | 12       |
| Refs    | a        | b        | c        | d        | a        | b        | e        | a        | b        | c        | d        | e        |
| Frame 1 | <b>a</b> | a        | a        | <b>d</b> | d        | d        | <b>e</b> | e        | e        | <b>c</b> | c        | c        |
| Frame 2 |          | <b>b</b> | b        | b        | <b>a</b> | a        | a        | <i>a</i> | a        | a        | <b>d</b> | d        |
| Frame 3 |          |          | <b>c</b> | c        | c        | <b>b</b> | b        | b        | <i>b</i> | b        | b        | <b>e</b> |

|         |          |          |          |          |          |          |          |          |          |          |          |          |
|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Num     | 1        | 2        | 3        | 4        | 5        | 6        | 7        | 8        | 9        | 10       | 11       | 12       |
| Refs    | a        | b        | c        | d        | a        | b        | e        | a        | b        | c        | d        | e        |
| Frame 1 | <b>a</b> | a        | a        | a        | <i>a</i> | a        | a        | <i>a</i> | a        | a        | a        | <b>e</b> |
| Frame 2 |          | <b>b</b> | b        | b        | b        | <i>b</i> | b        | b        | <i>b</i> | b        | b        | b        |
| Frame 3 |          |          | <b>c</b> | c        | c        | c        | <b>e</b> | e        | e        | e        | <b>d</b> | d        |
| Frame 4 |          |          |          | <b>d</b> | d        | d        | d        | d        | d        | <b>c</b> | c        | c        |

## What's the Impact of Memory misses on Running time?

Suppose that a program accesses uniformly at random 50 pages.

- Call  $x$  its running time with 40 frames.
- Call  $y$  its running time with 50 frames.

What's the ratio between  $x$  and  $y$ ?

## What's the Impact of Memory misses on Running time? (2)

What's the ratio between  $x$  and  $y$ ?

Suppose that a memory hit costs  $h$   
and a memory miss costs  $m$  ms.

- $x = 80\% \times h + 20\% \times m$
- $y = 100\% \times h = h$

$$\frac{x}{y} = .8 + \frac{m}{5h}$$

## What's the Impact of Memory misses on Running time? (3)

What's the ratio between  $x$  and  $y$ ?

Suppose that a memory hit costs  $h = 200ns = 200 \cdot 10^{-6}ms$   
and a memory miss costs  $m = 10ms$ .

$$\frac{x}{y} = .8 + \frac{m}{5h} = 10^5$$