

CS323 Operating Systems Memory Management V

Yuanyuan Zhou
Lecture 17
2/25/2003

Content of this lecture

- Administrative announcements
- Page replacement algorithms
- Multi-program memory management
- Summary

2

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Administrative

- Quiz2
- MP2

3

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Midterm1

- Time: 3/10, 7-8pm
- Content: 1,2,3, 4 except replacement algorithms
- Room:
 - DCL 1320, first letter in last name: A-L
 - MSEB 100, first letter in last name: M-Z
- Conflict exam

4

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Review

- Inverted page table
- Multi-level page table
- Demand paging
- Page Replacement
 - Optimal

5

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Principal of Optimality

- Description:
 - Assume that each page can be labeled with the number of instructions that will be executed before that page is first references, i.e., we would know the future reference string for a program.
 - Then the optimal page algorithm would choose the page with the highest label to be removed from the memory.
- This algorithm provides a basis for comparison with other schemes.
- Impractical because it needs future references
- If future references are known
 - should not use demand paging
 - should use pre paging to allow paging to be overlapped with computation.

6

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Optimal Example

12 references,
7 faults

Page Refs	3 Page Frames			
	Fault?	Page Contents		
A	yes	A		
B	yes	B	A	
C	yes	C	B	A
D	yes	D	B	A
A	no	D	B	A
B	no	D	B	A
E	yes	E	B	A
A	no	E	B	A
B	no	E	B	A
C	yes	C	E	B
D	yes	D	C	E
E	no	D	C	E

7

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

FIFO

12 references,
9 faults

Page Refs	3 Page Frames			
	Fault?	Page Contents		
A	yes	A		
B	yes	B	A	
C	yes	C	B	A
D	yes	D	C	B
A	yes	A	D	C
B	yes	B	A	D
E	yes	E	B	A
A	no	E	B	A
B	no	E	B	A
C	yes	C	E	B
D	yes	D	C	E
E	no	D	C	E

8

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Paging Behavior with Increasing Number of Page Frames



9

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Belady's Anomaly (for FIFO)

As the number of page frames increase, so does the fault rate.

12 references,
10 faults

Page Refs	4 Page Frames	Page Contents
A	yes	A
B	yes	B A
C	yes	C B A
D	yes	D C B A
A	no	D C B A
B	no	D C B A
E	yes	E D C B
A	yes	A E D C
B	yes	B A E D
C	yes	C B A E
D	yes	D C B A
E	yes	E D C B

10

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

LRU

12 references,
10 faults

Page Refs	3 Page Frames	Page Contents
A	yes	A
B	yes	B A
C	yes	C B A
D	yes	D C B
A	yes	A D C
B	yes	B A D
E	yes	E B A
A	no	A E B
B	no	B A E
C	yes	C B A
D	yes	D C B
E	yes	E D C

11

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Least Recently Used Issues

- Does not suffer from Belady's anomaly
- How to track "recency"?
 - use time
 - record time of reference with page table entry
 - use counter as clock
 - search for smallest time.
 - use stack
 - remove reference of page from stack (linked list)
 - push it on top of stack
- both approaches require large processing overhead, more space, and hardware support.

12

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

LRU and Anomalies

Anomalies cannot occur, why?

12 references, 8 faults

Page Refs	Fault?	4 Page Frames			
		Page 1	Page 2	Page 3	Page 4
A	yes	A			
B	yes	B	A		
C	yes	C	B	A	
D	yes	D	C	B	A
A	no	A	D	C	B
B	no	B	A	D	C
E	yes	E	B	A	D
A	no	A	E	B	D
B	no	B	A	E	D
C	yes	C	B	A	E
D	yes	D	C	B	A
E	yes	E	D	C	B

13

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Discussion

- Why does Optimal give the best hit ratio?
- What is the worst algorithm?

14

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

NUR: A LRU Approximation

- NRU: Evict a page that is NOT recently used;
LRU: evict a page that is LEAST recently used;
- NRU Implementation: simpler than LRU
 - additional reference bits
 - a register is kept per page
 - a one bit is set in the register if the page is referenced
 - the register is shifted by one after some time interval
 - 00110011 would be accessed more recently than 00010111
 - the page with register holding the lowest number is the least recently used.
 - the value may not be unique. use FIFO to resolve conflicts.

15

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Second Chance

- Only one reference bit in the page table entry.
 - 0 initially
 - 1 When a page is referenced
- pages are kept in FIFO order using a circular list.
- Choose "victim" to evict
 - Select head of FIFO
 - If page has reference bit set, reset bit and select next page in FIFO list.
 - keep processing until reach page with zero reference bit and page that one out.
- system v, r4 uses a variant of second chance

16

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Second Chance Example

12 references,
9 faults

Page Refs	3 Page Frames			
	Fault?	Page Contents		
A	yes	A*		
B	yes	B*	A*	
C	yes	C*	B*	A*
D	yes	D*	C	B
A	yes	A*	D*	C
B	yes	B*	A*	D*
E	yes	E*	B	A
A	no	E*	B	A*
B	no	E*	B*	A*
C	yes	C*	E	B
D	yes	D*	C*	E
E	no	D*	C*	E*

17

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Second Chance Example

12 references,
9 faults

Page Refs	3 Page Frames			
	Fault?	Page Contents		
A	yes	A*		
B	yes	B*	A*	
C	yes	C*	B*	A*
D	yes	D*	C	B
A	yes	A*	D*	C
B	yes	B*	A*	D*
E	yes	E*	B	A
A	no	E*	B	A*
B	no	E*	B*	A*
C	yes	C*	E	B
D	yes	D*	C*	E
E	no	D*	C*	E*

18

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou

Reminder

- Quiz2
- Mp2

19

2/28/2003

CS 323 - Operating Systems,
Yuanyuan Zhou