Clock Page Replacement Algorithm

Clock Algorithm Rules

- Page reference bit (or used bit) is set when page referenced.
- Pointer, a clock hand, initially pointing at 1st physical page.
- Page fault: look through physical pages for one to replace.
    - If clock hand pointing to page with ref set, reset and move to next page. [i.e., Second chance]
    - If clock hand pointing to page without ref set, replace with new page, move clock hand to next page.
    - If reach last page in memory without finding page to replace, clock hand moves back to first.
- Generally, when page fault, pick up search where left-off - with page in frame that the clock hand is currently pointing at.

Algorithm in pseudocode

```
func Clock_Replacement
begin
    while (victim page not found) do
        if (used bit for current page = 0) then
            replace current page
        else
            reset used bit
        end if
        advance clock pointer/hand to next page.
    end while
end Clock_Replacement
```

Example

Assume 3 frames of physical memory and a page reference string: 0414243424041424 34.

Represent memory frames as {p_1, p_2, p_3}, and reference bits for the pages in memory as {b_1, b_2, b_3}.

We'll use a hyphen, '-', to represent an unused frame, so initially our memory looks like this: {-, -, -}, and initially our reference bits look like this: {0, 0, 0}.

We add an underscore to the representation of memory frames to indicate the location of the clock hand. Initially it's at the 1st page, thus {_-, -, -}

As we process the reference string, we will highlight the references as they are 'consumed'.

i. Processing of the first few references is straightforward – in each case, a page is loaded and its reference bit set:

Continued

Reference string	Memory State, incl. clock hand.	Reference Bits
041424342404142434	{0, -, -}	{1, 0, 0}
041424342404142434	{0, 4, -}	{1, 1, 0}
041424342404142434	{0, 4, 1}	{1, 1, 1}

NOTE: In the slides for lecture 9, the bits are assumed to be zero at this point, making for a slightly different sequence of events. We assume that a page reference ALWAYS set the bit.

ii. The first reference after filling all frames is to a page in memory. Its reference bit is set. (No change visible, since already set when initially referenced.)

041424342404142434	{0,4, 1}	{1, 1, 1}

iii. The next reference is to page 2, which is not in memory. A page fault occurs, and the clock algorithm kicks into action:

041424342404142434	*{0, 4, 1}*	*{1, 1, 1}*
	{0, 4, 1}	*{0, 1, 1}*
	{0, 4, 1}	*{0, 0, 1}*
	{0, 4, 1}	*{0, 0, 0}*
	{2, 4, 1}	{1, 0, 0}

Initially, the clock hand references the first frame containing page 0. Page 0 has its reference bit set, so the bit is reset, and the hand moves to the next frame.

The next frame contains page 4, which also has its bit set. The bit is reset, and the hand moves to the next frame.

The next frame contains page 1, which has its bit set. The bit is reset, and the hand moves to the next frame. (Since the current frame is the last, this means that the hand returns to the first frame.)

The first frame contains page 4, which does not have its bit set. So, it is removed, page 2 is loaded, the reference bit for page 2 is set, and the clock hand moves to the next frame.

iv. The next reference is to page 4, which is in memory. Its reference bit is set.

041424342404142434	{2, 4, 1}	{1, 1, 0}

v. The next reference is to page 3, which is not in memory. A page fault occurs, and the clock algorithm resumes:

041424342404142434	*{2, 4, 1}*	*{1, 1, 0}*
	{2, 4, 1}	*{1, 0, 0}*
	{2, 4, 3}	{1, 0, 1}

The hand currently points at frame 2 containing page 4. The page reference bit is set, so its reference bit is reset, and the hand moves to frame 3.

Frame 3 contains page 1, and the page reference bit is not set, so it is removed, page 3 is loaded, the reference bit for page 3 is set, and the clock hand moves to the next frame. (Which in this case is back to frame 1.)

Continued

vi. The next reference is to page 4, which is in memory. Its reference bit is set.

04142434**2**404142434	{2, 4, 3}	{1, 1, 1}

vii. The next reference is to page 2, which is in memory. Its reference bit is set. (No obvious chance since already set.)

04142434**2**404142434	{2, 4, 3}	{1, 1, 1}

viii. The next reference is to page 4, which is in memory. Its reference bit is set. (No obvious chance since already set.)

04142434**2**04142434	{2, 4, 3}	{1, 1, 1}

ix. The next reference is to page 0, which is not in memory. A page fault occurs, and the clock algorithm resumes:

04142434**2**404142434	*{2, 4, 3}*	*{1, 1, 1}*
	{2, 4, 3}	*{0, 1, 1}*
	{2, 4, 3}	*{0, 0, 1}*
	{2, 4, 3}	*{0, 0, 0}*
	{0, 4, 3}	{1, 0, 0}

The hand currently points at frame 1 containing page 2. The page reference bit is set, so it is reset, and the hand moves to frame 2.

Frame 2 contains page 4. The reference bit is set, so it is reset, and the hand moves to frame 3.

Frame 3 contains page 3. The reference bit is set, so it reset, and the hand moves to frame 1.

Frame 1 contains page 2. The page reference bit is not set. Page 2 is removed, page 0 is loaded, the page 0 reference bit is set, and the clock hand moves to the next frame.

x. The next reference is to page 4, which is in memory. Its reference bit is set.

04142434**2**404142434	{0, 4, 3}	{1, 1, 0}

xi. The next reference is to page 1, which is not in memory. A page fault occurs, and the clock algorithm resumes:

04142434**2**404142434	*{0, 4, 3}*	*{1, 1, 0}*
	{0, 4, 3}	*{1, 0, 0}*
	{0, 4, 1}	{1, 0, 1}

The hand currently points at frame 2 containing page 4. The reference bit is set, so it is reset, and the hand moves to frame 3.

Frame 3 contains page 3. The reference bit is not set, so page 3 is removed, page 1 loaded, the page 1 reference bit is set, and the clock hand moves to the next frame.

xii. The next reference is to page 4, which is in memory. The page reference bit is set.

04142434**2**404142434	{0, 4, 1}	{1, 1, 1}

Continued

xiii. The next reference is to page 2, which is not in memory. A page fault occurs, and the clock algorithm resumes:

Continued

041424342404142434	*{0, 4, 1}*	*{1, 1, 1}*
	{0, 4, 1}	*{0, 1, 1}*
	{0, 4, 1}	*{0, 0, 1}*
	{0, 4, 1}	*{0, 0, 0}*
	{2, 4, 1}	{1, 0, 0}

The hand currently points at frame 1, containing page 0. The reference bit set, so it is reset, and the hand moves to frame 2.

Frame 2 contains page 4. The reference bit is set, so it is reset, and the hand moves to frame 3.

Frame 3 contains page 1. The reference bit is set, so it is reset, and the hand moves to frame 1.

Frame 1 contains page 0. The reference bit is not set. Page 0 is removed, page 2 is loaded, the page 2 reference bit is set, and the clock hand moves to the next frame.

xiv. The next reference is to page 4, which is in memory. Its reference bit is set.

041424342404142434	{2, 4, 1}	{1, 1, 0}

xv. The next reference is to page 3, which is not in memory. A page fault occurs, and the clock algorithm resumes:

041424342404142434	*{2, 4, 1}*	*{1, 1, 0}*
	{2, 4, 1}	*{1, 0, 0}*
	{2, 4, 3}	{1, 0, 1}

The hand currently points at frame 2 which contains page 4. The reference bit is set, so it is reset, and the hand moves to frame 3.

Frame 3 contains page 1. The reference bit is not set, so page 1 is removed, page 3 loaded, the page 3 reference bit is set, and the clock, hand moves to the next frame.

xvi. The next reference is to page 4, which is in memory. Its reference bit is set.

041424342404142434	{2, 4, 3}	{1, 1, 1}

And done!