Operating Systems

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School of Software, CAU

**Project #2**

**- Implementation of Memory Management Schemes –**

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**1. 요구사항 1: Page Allocation 정책 구현**

**(1) Pintos에서의 Page Allocation 과정에 대한 이해와 분석**

* Page Allocator: User pool & Kernel pool

Pintos의 Page Allocator의 구조를 살펴보자. Pintos에서는 **“threads/palloc.c”**에 Page Allocator가 정의되어 있다. Pintos는 System RAM을 절반으로 나누어 사용하는데, 절반은 user pool (= virtual memory pages), 나머지 절반은 kernel pool이라는 “pool이라고 정의된 구조체를 통해 각각에 대해 관리한다. 각각의 Pool은 Mutual Exclusion을 위한 lock과, pool에서 page를 저장하는데 사용할 memory인 bitmap, 그리고 pool의 시작주소인 base를 멤버로 가지고 있다. 우리는 Page Allocation를 위해 pool이 저장된 메모리 내부를 표현해주는 bitmap에 대해 살펴보았다. 이는 **“lib/kernel/bitmap.c”**에 선언되어 있다.

**“threads/palloc.c”**는 **palloc\_init()** 함수를 통해 Page Allocator를 초기화하고, **palloc\_get\_multiple()** 함수를 통해 Page Allocation을 실행하며, **palloc\_free\_multiple()** 함수를 통해 할당된 page를 할당 해제한다. 우리는 Page Allocation 정책을 구현하는 것이 목표이므로, **palloc\_get\_multiple()** 함수에 대해 살펴보았다.

**Palloc\_get\_multiple()** 함수는 파라미터 palloc\_flags가 PAL\_USER인지에 대해 체크하고, PAL\_USER이면 user pool에, 그 외의 경우에는 kernel pool에 접근한다. 그 후, pool이 가지고 있는 lock을 acquire하여 Critical Section에 접근하고 **“lib/kernel/bitmap.c”**에 정의되어 있는 함수인 **bitmap\_scan\_and\_flip()**을 호출한 뒤, lock을 release하여 Critical Section을 빠져나온다. 그 후, **bitmap\_scan\_and\_flip()**이 return한 index를 통해 pool의 현재 상태를 refresh하고, condition check를 하여 예외처리를 한 뒤, 할당한 page들을 return한다. 여기서 Page Allocation을 구현하여야 할 부분은 Critical Section에 접근하여 호출하는 함수에 해당할 것이다. 따라서, 우리는 이미 구현되어 있는 First-fit을 제외한 나머지 세 정책을 구현한 함수를 **“lib/kernel/bitmap.c”**에 정의하여 **bitmap\_scan\_and\_flip()**과 같은 위치에 호출하여야 한다.

* Memory Allocation: Bitmap, First-fit

**“lib/kernel/bitmap.c”**에 선언되어 있는 Bitmap 구조체는 pool의 메모리 구조이며, 미리 구현되어 있는first-fit 정책에 대한 함수인 **bitmap\_scan\_and\_flip()**을 통해 Page Allocation에서의 bitmap의 역할을 살펴볼 수 있었다. **bitmap\_scan\_and\_flip()**은 pool의 bitmap의 주소와 bitmap 탐색을 시작할 위치(bitmap의 가장 앞부분인 ‘0’), 할당할 page의 크기, 탐색할 value를 파라미터로 받는다. 그리고 **bitmap\_scan()**함수를 통해, first-fit의 정책 알고리즘대로 bitmap의 가장 앞 부분부터 탐색하여 할당할 page의 크기만큼의 value로 이루어진 공간을 탐색한다. 이 과정을 통해 할당할 수 있는 bitmap의 위치를 찾으면 해당하는 위치의 index를 return하고, 찾지 못한다면 BITMAP\_ERROR(비트맵의 한계 크기로 선언되어 있음)을 return한다. 이를 통해, 우리가 정책을 구현할 함수에서 실행해야 할 것들은 bitmap에 대한 탐색과 할당 가능 여부 체크, 그리고 할당 및 index return임을 분석하였다.

**(2) 각 Page Allocation 정책 함수의 선언 및 호출**

* 각 Page Allocation 정책 함수에 대한 선언은 아래의 그림 1과 같다.

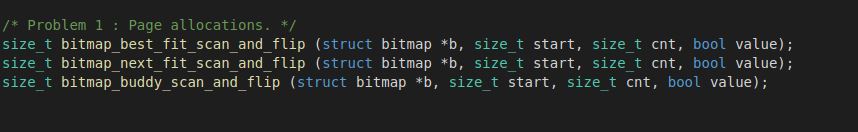


그림 1. 각 Page Allocation 정책 함수의 선언(“lib/kernel/bitmap.h”)

* 각 함수에 대한 호출은 아래의 그림 2와 같다.

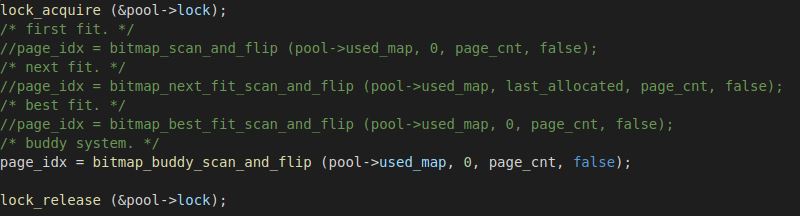


그림 2. 각 Page Allocation 정책 함수의 호출(“threads/palloc.c”)

**(3) Next-fit의 구현**

* Next-fit의 알고리즘

Next-fit은 가장 최근에 배치되었던 메모리의 위치에서부터 검사를 시작하여 크기가 충분한 다음 위치의 사용 가능한 메모리 블록을 선택하여 할당해주는 정책이다. 따라서, 우리는 Next-fit의 start 파라미터로 마지막으로 배치된 메모리의 위치를 넣어주어야 한다. 이를 위해, Palloc\_get\_multiple()함수에 last\_allocated변수를 static으로 선언하여, 마지막으로 배치된 메모리의 위치를 저장하도록 하였다. last\_allocated의 초기값은 0으로 초기화하였다.

Next-fit의 알고리즘은 마지막으로 배치된 메모리의 위치에서부터 검사를 시작하는 것을 제외하면, First-fit의 알고리즘과 일치한다. 따라서, Next-fit을 구현할 때, Next-fit을 호출할 때 start를 last\_allocated로 입력하게 하고, Next-fit 함수가 받은 파라미터를 First-fit이 구현되어있는 함수인 **bitmap\_scan\_and\_flip()**의 파라미터로 입력하여 호출하였다. 그리고, 첫 번째로 부른 **bitmap\_scan\_and\_flip()**가 BITMAP\_ERROR를 return하면 마지막으로 배치된 메모리의 위치 뒤로는 할당할 수 있는 공간이 없다는 뜻이므로, start 파라미터를 0으로 입력한 **bitmap\_scan\_and\_flip()**을 한 번 더 호출하여 bitmap의 가장 앞부분부터 마지막으로 배치된 메모리 앞 부분까지의 빈공간을 탐색하도록 하였다.

* Next-fit의 구현 코드는 아래의 그림 3과 같다. Next-fit의 역할과 구현, 반환값을 주석으로 설명하였다.

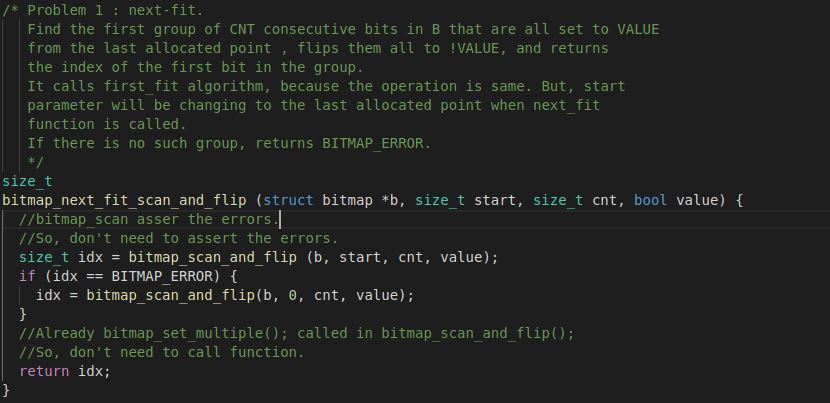


그림 3. Next-fit의 구현 코드(“lib/kernel/bitmap.c”)

**(4) Best-fit의 구현**

* Best-fit의 알고리즘

Best-fit은 요청된 크기에 가장 근접한 크기의 메모리를 찾아서 할당해주는 정책이다. 따라서, 우리는 Best-fit을 통해 bitmap 전체를 탐색하여 파라미터로 받은 cnt에 가장 근접한 공간을 찾아서 할당한 뒤, 그 공간의 시작 index를 return해주어야한다.

우리가 구현한 Best-fit은 다음과 같다. bitmap전체를 탐색하면서 할당 가능한 시작점(avail\_start로 선언하였다.)과 할당 가능한 끝점(avail\_end로 선언하였다.)을 통해 가장 근접한 크기의 빈 메모리 공간을 찾는다. 탐색을 위해 avail\_start는 start로, avail\_end는 start+1로 초기화하였다. 빈 메모리 공간은 min\_size로 선언하고 처음 찾은 빈 공간과의 비교를 위해 SIZE\_MAX로 초기화하였다. avail\_start의 메모리가 비어 있지 않으면 avail\_start와 avail\_end의 값을 1씩 늘려서 한 칸씩 이동하고, avail\_start의 메모리가 비어 있으면 avail\_end의 값만 하나씩 늘린다. 이 과정에서 avail\_end가 bitmap의 끝까지 탐색을 마쳤거나 avail\_end의 메모리가 비어 있지 않았을 때, avail\_start부터 avail\_end까지의 빈 공간이 저장되어 있는 min\_size보다 작고 cnt의 크기가 들어갈 수 있으면, min\_size에 빈 공간의 크기(avail\_end – avail\_start)를 저장하고 return할 index에 avail\_start를 저장한 뒤 avail\_start의 값을 avail\_end로 옮기고, avail\_end의 값을 1 늘린다. 이를 통해, bitmap 전체의 빈 공간 중에 cnt의 크기에 가장 근접한 크기의 메모리를 찾을 수 있다.

* Best-fit의 구현 코드는 아래의 그림 4와 같다. Best-fit의 역할과 구현, 반환값을 주석으로 설명하였다.

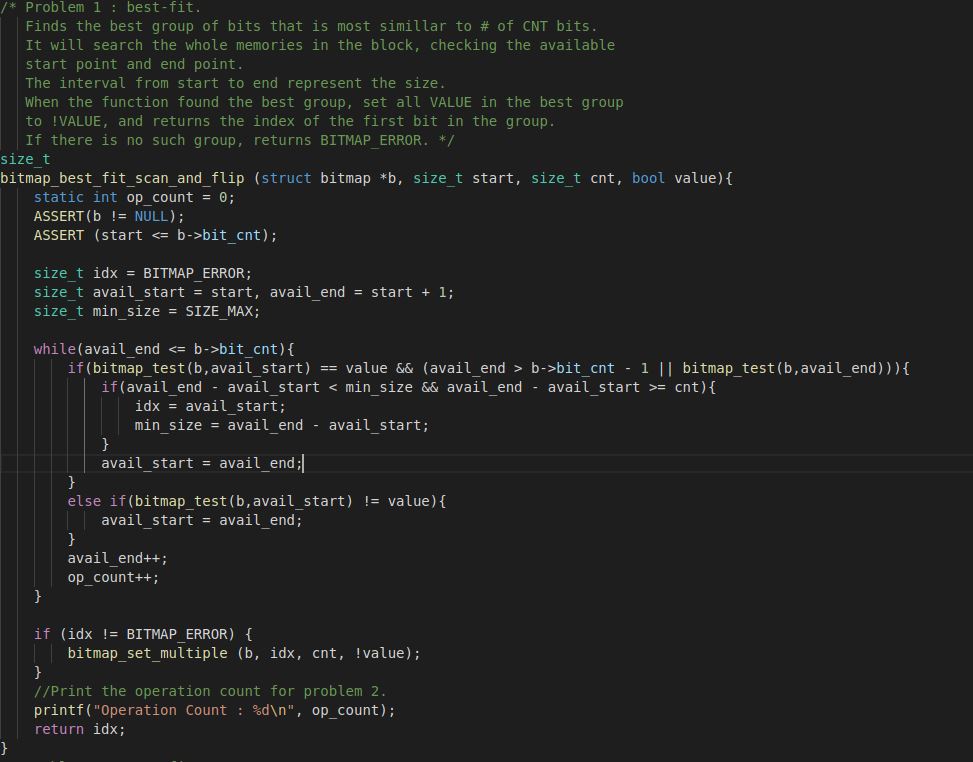


그림 4. Best-fit의 구현 코드(“lib/kernel/bitmap.c”)

**(5)Buddy-System의 구현**

* Buddy-System의 알고리즘

Buddy-System은 크기의 메모리를 반으로 나누어 가며 할당할 수 있는 최소한의 크기를 탐색한다. 반으로 나누는 것을 할당할 수 있는 최소한의 크기를 탐색할 때까지 반복하며, 반으로 나누어진 메모리 공간을 list에 추가하는 알고리즘이다.

처음 구현할 때에 Buddy-System의 알고리즘대로 list에 반으로 나누어진 메모리의 크기를 지속적으로 저장하는 방법을 통해 구현하려고 하였으나, list의 index가 유동적으로 변하는 list를 구현하기 위해서는 Memory Allocation이 필요한데, Memory Allocation을 위한 malloc을 call할 때, 이미 Page Allocator에서 Page를 할당하기 위한 함수인 **Palloc\_get\_multiple()**에서 pool의 lock이 acquire되어서 kernel panic상태에 빠져버리게 된다. 그래서 우리는 Buddy-system을 구현할 때, 할당할 수 있는 최소한의 크기를 저장하여, bitmap의 가장 앞에서부터 그 크기만큼 index를 옮겨가며 할당할 수 있는 부분을 찾아 할당하게 하였다.

* **![스크린샷이(가) 표시된 사진

  자동 생성된 설명](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDcRXhpZgAATU0AKgAAAAgABAE7AAIAAAAKAAAISodpAAQAAAABAAAIVJydAAEAAAAIAAAQzOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAOq5gOyYge2YhAAABZADAAIAAAAUAAAQopAEAAIAAAAUAAAQtpKRAAIAAAADMjgAAJKSAAIAAAADMjgAAOocAAcAAAgMAAAIlgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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CiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAq5e/8emn/APXuf/RslU6uXv8Ax6af/wBe5/8ARslAFOtLSmW1SfUHI3wLthUnkyNwD+AyfwFZtFJq6sJq5o6Rsinlv5tpFqu9FY/fkPCj8+foKz3dpHZ3JZmOST3NJT4ommmSKMAu7BVBIGSfc0W1uG2pe0S8jsb2WaZlH+jyqu5NwLFSACMHv68U+21aSXV7Ca+kVYbaZSFjjCqi7gThVH9Kz7i3ktLqW3nAWWFyjgMGAIODyOD+FNRHlkWONWd2IVVUZJJ6AClypu4nFa3JW23N8+6ZY1dyfMkDED3OAT+lbMtzZR+I7G+S+ilijaEPsSTK7FUE8qOOO3NYUsUkEzxTxtHJGxV0dcMpHBBB6Grmo6JfaTFC+oRxRGZQyx+fG0gBAILIGLLkEH5gKTS01G43Yr3ULaHJBvzK135oXB+7tIzn607V5Le6kjure5Ri0UaNCVYMhVAp7Yxx2PeqtxY3FpBbS3EexLpDJDlhllyVzjqBkHr1xTZrS4tv+Pi3li+Yr+8QryMZHPcZH50cqTDl1v8A1qQ1pXslvdaZZslyizW8PlNCytuJ3scg4xjDdyKq3FheWsMct1aTwxyfceSMqH+hPWq9U0mNrU3JtRtnvr+QS5SaxWFDtPLBUGOn+yamu9WSeNri3vbeBngEbQmyUyZ2bSofb0Pruzg1ztFR7NEci/r+vIK6Czv7FZNOvZrny5LGLY1vsYmQgkjBAxg55yRXP0/yZfIM3lv5QbYZNp27sZxn1qpRUlqU48x0UD2kNnol3dXXlG33yeUEJMgEpOFxxnIxziorfVYpdPgjFzbWksEjt+/tBKCGbcCp2sQR0xx2rGWO4uLV3BLxWqjIZx8gLdgT6ntUFR7NPcnk7mmt8jWOqrLNumupEZTtx5mGJJ44HXOKdps9rFYyBpLeG580HfcW/mgpjoo2kA59cfWsqiq5Faw+VG9LqFnL4kv5hNtt7qJ41lKHAJXAJAGcZ9qq6QLa01yGae+gWK3lV9+2Q+YM/wAI25/PFULa1uLyYQ2kEs8p5CRIWY/gKSaCW2maG4ieKVThkkUqw+oNLkSVr9A5NDStXtYBfWcl5GUuo1C3CI5VSGDYIKhscelWJdRtFWSCOYusenfZkk2keY+8Nx3A5I5x0rBopuCYcuty9qFxFPb2CxNuaG22PwRht7HH5EU3SbtLHVIbiYMUUkNt6gEEZHuM5qqiPLIscas7sQFVRkk+gFI6NG7I6lWU4KkYIPpTsrWHy6WNSze00rV7a4W8W6jDHeY42BQEYz8wHPOcD061Zt76z0xLOKO4+1iO9Fy7ojKFUDGPmAOawaKTgnuS4p7m6tzY2trFEl4szDUFnYpG4AQDryBz7VXuL2CS01NFky092skYwfmUF8n26isyON5ZFjiRndjhVUZJPoBTp7ea1maG6hkhlX7ySKVYfgaXIv6+Q+XqXtQkt7qxtJY7lBLDAsTwMrbsgnkHGMc+tZtTw2dxcW800MZeODb5hBHG44HHU8+lRzQy28zwzxvFLGxV0dSrKR1BB6GqVloUlZFue4ifRLO3Vsyxyys64PAO3H8jWl9vsvN/tD7T+8+xeR9l2Nnd5ezrjG3v1z7Vz9TfZLnyPO+zy+Vt3eZsO3bnbnPpnj60nFNE8tyxNcxvoVpbK+ZI5pXdcHgELg/oao0UVSVhpWR0dv8AZY9L0W4urvyPIlkk2bGYuA4OFx3474rP+3RvpupITskubiORYwDyAXJ/LIrOaWRo0RnYomdqk8LnrgdqbUKHf+tbkqJrWktpcaXDa3N39ka3uGlyUZg6sF6YB5G3v69aszXtlqUGoLLdC0a4vRPGHRmG3DDnaDzzWBRTcE2PlNv+07WTxNJcszJbyRtD5hXJAMewMR+tN026gsRe2huYCJgmy4aDzI8qc4Ksucc9cdRWNRRyK1g5Vax0UWqwpNi5vY5gklvtaK38tQquSQAFHTPpWdqd1DcQWqwvuMYk3cEYzIxH6Gs6nwwy3M6Q28byyyMFSNFLMxPQADqaFTSdwUUtSfTorSa+RdQn8i36u+0nPtwD19cVPrEiS3CNFdQzRhdqRwo6rEo6D5gPz+tU4reWa6S2RcSu4jCuQvzE4wSeBz60lxBLa3MtvcIY5onKOjdVYHBFO2qY7a3H3kcEN06Wlx9ohGNsuwru454PvUFFFUhhRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAVcvf+PTT/8Ar3P/AKNkqnVy9/49NP8A+vc/+jZKAKddZ4ZQx+DvEN9Bp9td3Vs9t5bz2yzeSrM4YgMCPQcjH5VydbGk+I7rRtIvrSweaCe6kikW5hmMbRbN3Axzzv8AUdKmSbjZeX5gdVHp9ha+PpfO022Zf7Ge7msXT93HMbUuV2/w4bnA6dsVzen6zNd+JbCWW004ZkWFkXT4RGylucpt2k4OM4z71ki/uxdSXIupxPMGEkvmHc4YYYE9TkEg+tOsNTv9KnM+l3tzZSsu0yW8rRsV64ypHHApRjZ3f9bg9Y2/rZf8OdXp1vaRfEHxCr2NtNBaxX7xQSRAxqUDlfl7YwOlO+1iGfwnq8VtYxXN4WjuNtnEI22z7Q2zbtDY7gA8Vy9zr2r3s/nXmq3txL5bReZLcOzbD1XJPQ5OR0qq9zPJDFFJNI8cOREjOSseTk4HbJ54pRg1y36W/X/MctU/P/gHQeLNWux43v3khs1e1vJlRfsEIBG8/fXZhz7tmrHxH1Ca68WXEEiWypEsRUxWscbHMSdWVQW+hJx2rnb7VdR1Pyv7Sv7q88kbY/tEzSbB6DJ4qC4uZ7udprqaSeVsbpJGLMcDA5PsMUo07JeQ27u5v+OcL4kRYv8Aj3WytRb+nl+SmMfrVdNak1XV7IaksIhF75z7QQPmKhs5PTC1nXeoT30NrHclW+yxeTG2Pm2ZJAJ74yce1Va1sr3Em0rHYX/2r7L4p/tHzNv2lPL8zON/mHGM/wCznp2qXWbSNrzXbaXT7e1trSFJIJI7dUKsWUD5gMncCeD+HSuSn1C8uoo4rq7nmji/1aSSFgn0B6Vb1jXLvV7qZnlmS3eTetsZiyIfYdP0rFU2rf12/wAjodWLu/66nQa3HpVmt7YR2kzrHCDAyaeg2nAIkM2/cwPfIxz0FZl1dJYeHdJ+z2doZLiGUyyyW6uz/vGA5I4x6jnpzWQdSvjZi0N7cG2HSEyts/75zioXmlkjjSSR2SMEIrMSFBOSAO3NNQfUl1F0R2Om6fbPbx6feJFJJJYPcbYrBfkGwsrGbcGz06AjtWfb6lcR+B5PLjtWEd4ifNaRNgFG5OV5PuefesZNV1CK3WCO+uUhXIWNZmCjPXAzjufzplrf3ljv+xXc9v5gw/kyFNw9DjrQ4N3v/WoKola3n+Vv+CaWnMsvhnVkkhgbyUjeNzCm9SZAD8+N3Ttmr+lQrDp2keRp8F4b66eO5aWESHAKgICfu8HORg81iW+t6rZwLBaaneQRL92OK4ZVH0ANRQajfWyyLbXlxCs3+sEcrKH+uDzTcXqSpJWOhP2bTNOc2ttaz41eSFZZ4VkJjAHy8g8H/wDVWHrlvHaa/f28C7Yorh0RfQBjgVVE8ohEQlcRq28JuOA3rj196bLLJNK0sztJI5LM7nJY+pNOMWnf+ugSmpK1v61/z/A3NM8z/hD9U+xbvtHnxebs+95OG9O27GfwpdLSSPTtUvprcXN7brEEW5j8zYjHBba3B4CjkcZrFtrq4s5hNaTywSjgPE5Vh+IqRNSvo7xruO9uFuW6zLKwc/8AAs5ocXd+YKaSV+h0d5YW6y6kRaRxytpUVw0IT/UyFkLbR/DwSfbNSR2sFookeygZ10IThZIgRv8AM4cjucVyyX13Fdm6iupkuCSTMshDnPX5utLJqF5KzNLdzuzJ5bFpCSVznafbPOKlwdrX/rUpVIp3t/Wn+R0KTCDXNAvIobaOS7jjMwFumwnzSu4LjCnCjkAVka/czXGtXQnSJDHM6gRwJH/Eeu0DJ9zzVB5pZFjEkjsI12oGYnYM5wPQZJNSXV/d3zI17dTXJQbVM0hfaPQZ6VXLZ39SXO8WvT8EQVd1ZVW/ITT308bE/cOxYj5R82Tzz1/GqVST3E11L5lzNJNJgDdIxY4AwBk+1V1M76EunXL2moQzxvGjK33pASoB4Occ4we3NdBdWkOoW8E6iERiNR1dTHCJNpZFORjJP3mJPoK5apheXIszai4m+zFtxh3nZn129M0mrtMqMrJpnW6g+NL8S2yWEFtDazRRRtFEFO0ScBiPvEgZycmsrXf+JnpllricySD7Nef9dkHDH/eTB+oasuXU7+e3FvNe3MkIAURvKxXA6DGcUQahPb2F1ZoVMF1tMisM4KnII9DyR9CazUGvX+r/AOZc6ik/69TsNQjtZbjVdPWws4obfSIriNo7dVcShIyW3gZ53HIzj2zXKjWrkaZ9g2x+V5Jhzg7tpk8z165H5VWN9dtJI7XUxeSPynYyHLJgDaT3GAOPYVBVRhbcjn00/rYmWzuWsXvFt5TbI4jaYIdisRkKT0zjtUNXjq9z/YA0ddi2v2k3LYB3O+0KMnPQDOPqao1p1I6HoGgWkUdl4Xgg0e1votXnkS+lltxI3Em0qHPMe1MNkEdc0lpbLZeHbFtL0m01DzdbmtWnltEmZ4wE2pkg4zknI5HYjmuMtdX1KxtZbay1C6t4Jv8AWxQzMiyfUA4P41eg8T31n4ft9M06e4s2imlkeaC4ZDIHCDaQMcDZ696d9b/1uhf1+DK/iK0t7DxNqdpYnNtBdSRxc5+UMQOe9avh+NLbwrquq29jBe30E0MSieETLBGwYs+xgQeVUZIOM+9YsMemNCrXN5dpKfvKlqrgfiZBn8qIb6bS74zaJf3cBxgTITC+O4+Vj/OpWisU9Xc6PTSyaLresrpNpJqMc9vGIHtFaOCNwxZxEQVGSqjpxnjGava5pNjBa+JDBYwxTpa2M5iWPm2d9pkVc8qMtjHviuOg1nU7a/e+ttRu4buTO+4jnZZGz1ywOTTbfVdQtLx7y1v7qG5kzvnjmZXbPXLA5Oae4juJ7O20u51V20y0MttoFpKsc1urBJW8kF9pGN3zHOevOc80yznWy8feFrq1trOFtRgtXuFFrGU3NJgsqlcITtByuMc4xXEy6nfzNK017cSNNGIpC8rEugxhTzyBgcewqKS6uJWiaWeVzCoSIs5PlqOQB6Aegp31T8/8/wDP8BW0t5f5f5fiXtfvbi81qc3UcEUkUjIFgtY4OjHqEUZPuea0PHYH/CY3BI/etFA0w/6aGJC/47s1lT6zqF5fQXeo3c1/LARsN3I0vAOQvzHpntUNxezXeoSXt23nTSymWQv/ABsTk5qYqySKk7tsteIERNbnEekyaOuFxZSOzNH8o7sAeev41m1d1fVbnW9XuNRvipnuH3MFGFXsAB6AYA9hVKhbCCiiimAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAVcvf+PTT/APr3P/o2SqdXL3/j00//AK9z/wCjZKAKdaGj6YmqTXCy3ItkggadnKbuFxxj8az6uafqH2AXY8vzPtFu0H3sbc459+nSmrdRxtdX2L+n+H49VnnOnz3U1tbxhpGWzLS5JwFEasc/XIGKt2vhy3tPFVlYas1wYbnY8amAozgnG1wWBToemayNN1JLOK5t7m3+02tyoEkYfYwIOQwbBwR9D1pYtShs9atr7T7QxJburiKSXeWIOeTgdfYVacbou8LbakkWmWt5fTw2N1MY4reSYtNAEOUBO3Ac8cdc/hSwaJ57aQPtG3+0pCn3P9Xh9uevPr2og1S0s9Va5tLKUQSRvHLDJcBiQ4IOGCjHB44PTvUra9ClxpLW1k0cWmvuVWm3GT593J2jB/CiPLdXG+Sz/rt/wRYdDsrnWotNt9SdpWkaOSQ2+EXAJyDuyw49BVW+02GDT4L2zumuIZZHiO+LyyrKAemTkYYc/pSafqn2HXF1HyfM2uzeXux1BHXHvUb3+/RYrDy8eXO83mbuu5VGMf8AAf1qFbl13/4b/gg+TW3n/wAAqoFMiiQlUyNxUZIHsOM10OuaODqOi2mmSLOL20i8hjarbs252UbwGYFs9Wz6elc/CYlnQ3CO8QYb1RwrMO4BIOD74P0rodT8S2Fy2mT6Zp13aXemJHHBJLerKpVGLDKiJecnrnHtRppfv+Bjrr6Gjc6FpOneEte+zXy6hc2t3bwSSNa7GiOXDbCScqcdeM45HSszU/C0emaS2pvqKSWc4X+z3WP5ron72V3fJs5DdecDnOakvvFGn3Gl6jaWujyW7alcx3E8hu9+CpJKoNgwvzHGSSPU0zUvFo1PTptOm09VsUC/2fCknNkV4yGx824Z3Zxk88Yqdbeen5K5Wl/IyJ9PEGk2t99stZDcO6m3STMsW3HLr2Bzx64qnWrfPpI8PaZFZR7tRzK95N8wwC2ETB44AzketZVMXQKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKuXv8Ax6af/wBe5/8ARslU6uXv/Hpp/wD17n/0bJQBTooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKvG2vb3TUuILGd7ayTy5Z0jZkUl2YbmAwv3u/pVGul8DDzdYvLd5BFFcadcxySt92JfLJ3t3IGB0yfQUdGHVHNUU+aNYp3jSVJlViBJGCFceo3AHB9wDTKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACtbR9Yg0i1vsWjy3d1bvbJKZgEjRxhjs25Jx0O4D2NFFHSwGTRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQB//9k=)**Buddy-System의 구현 코드는 아래의 그림 5와 같다. 주석을 통해 구현방법과 반환값을 설명하였다.

그림 5. Buddy-System의 구현 코드(“lib/kernel/bitmap.c”)

**2. 요구사항 2: Page Allocation 정책의 성능 평가**

**(1) 성능 평가에 대한 기준과 기준 선택 이유**

* Fragmentation: 전체 bitmap 중 사용한 부분(맨 앞의 할당한 부분 ~ 맨 뒤의 할당한 부분)에서의 빈 공간.

각 정책의 같은 양의 Allocation에 대한 Fragmentation의 수는 각 정책의 Memory Resource 관리 효율에 대한 지표가 된다. 따라서, 각 정책으로 구현된 Page Allocation에 대해 같은 테스트를 실행하고 각각의 Fragmentation 수를 비교하여 Page Allocation 정책의 Memory resource에 대한 성능을 평가할 수 있다.

* Operation Count: 할당 공간을 탐색할 때 필요한 연산(반복문의 반복시에 실행되는 연산)의 횟수.

각 정책의 같은 양의 Allocation에 대한 Operation Count는 각 정책에서 실질적으로 할당에 필요한 시간을 나타낸다. 이를 비교하여 Page Allocation 정책의 실행속도를 비교 및 평가할 수 있다.

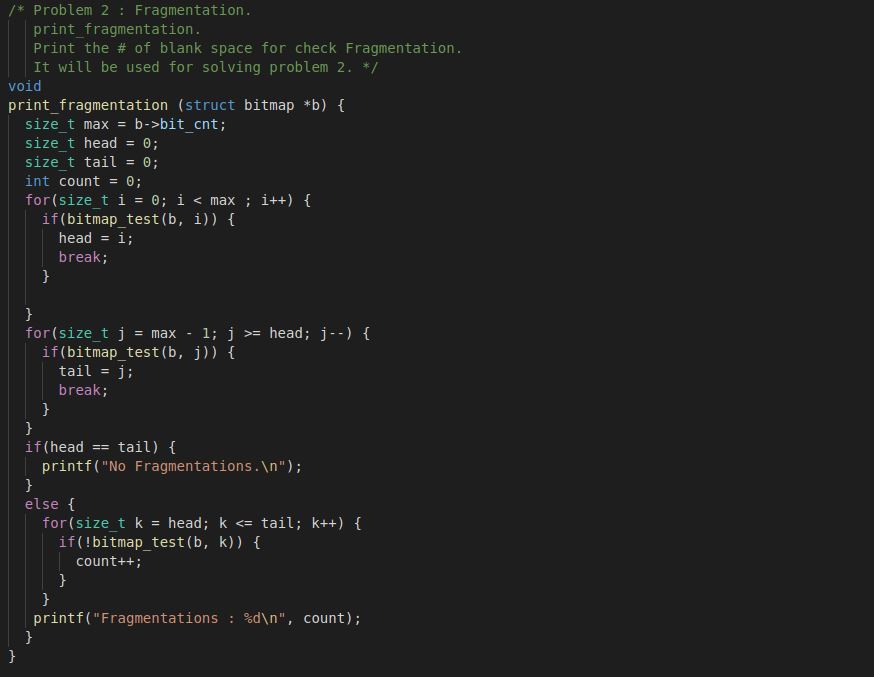
**(2) 성능 평가를 위해 작성한 코드****(그림 6)**.

그림 6. Fragmentation 출력 코드(“lib/kernel/bitmap.c”)

* Operation Count는 그림 3, 4, 5의 코드에 static int로 선언되어 있다. 연산을 할 때 마다 1을 더하며, Page Allocation이 끝날 때 마다 출력하게 하였다.

**(3) 각 정책의 테스트 결과**

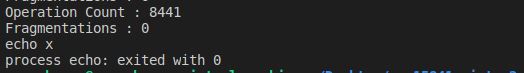
* 테스트는 examples에 있는 echo를 실행하였을 때의 Page Allocation으로 하였다.
* ****테스트 결과(그림 7-1, 2, 3 ,4)

그림 7-4. Buddy-System의 테스트 결과

그림 7-3. Best-fit의 테스트 결과

그림 7-2. Next-fit의 테스트 결과

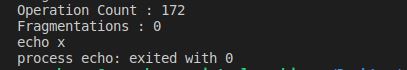


그림 7-1. First-fit의 테스트 결과

**(4) 기준을 통한 정책의 비교 및 분석**

* Best fit은 한 번 할당할 때 bitmap 전체를 반드시 탐색하기 때문에 Operation count의 값에서 엄청난 비효율성을 보였다. 따라서, 좋지 않은 알고리즘이라고 판단된다.
* Next fit은 마지막으로 할당된 bitmap에서의 위치 다음부터 연산하기 때문에 Operation count에서 큰 강점을 보였으나, 테스트를 진행한 경우와 같은 간단한 상황에서도 가장 많은 공간을 사용하였고, 앞서 사용한 공간에 대한 할당의 해제가 일어날 때 Fragmentation을 보였다. 이는 따라서, Next-fit 역시 좋지 않은 알고리즘이라고 판단된다.
* Buddy system은 공간의 탐색 이전에 할당할 크기에 대한 비교가 필요하기 때문에, Frist fit과 비교하였을 때 Operation count가 더 크다. 그리고, 2의 지수 승 크기에 한정되어 있기 때문에, 메모리 할당이 복잡해지면 Fragmentation이 발생할 확률이 생길 것으로 예측할 수 있다.
* 위의 결과와 분석에 따라서, First fit이 대부분 상황에서 가장 효율적인 알고리즘이라고 판단된다.

**3. 요구사항 3: Frame Table 구현**

**(1) Pintos에서의 Frame Table에 대한 이해와 분석**

* PintOS는 kernel virtual address가 1개의 physical address로 mapping된다. 앞서 언급했듯이 사용 가능한 physical memory의 절반은 kernel, 나머지 절반은 user pool에 할당된다. 또한 각각의 pool은 가지고 있는 page들의 할당 상태를 저장하기 위해 bitmap을 사용하며, bitmap을 저장하기 위해 필요한 공간을 제외한 나머지 공간을 frame으로써 사용할 수 있게 된다. 프로젝트 기본 설정 기준으로, PintOS는 3,968KB의 main memory로 부팅하며, kernel pool과 user pool에 각각 367개의 page를 할당해 준다.
* 프로젝트 문서에 언급된 대로, frame table은 swap out 할 page를 찾기 위해 사용된다. 최근 참조/수정 이력에 따른 replacement policy를 적용하기 위해 frame table entry 각각에는 해당 page가 참조되었는지에 대한 정보가 반드시 있어야 한다. user virtual address를 physical address로 변환하는 과정은 하드웨어적으로 이루어지고, 이를 통한 page로의 접근 내역은 page directory의 주소를 cr3 레지스터에 등록한 프로세스의 page table에 존재한다. 따라서 frame table이 가지고 있어야 하는 요소는 다음과 같다.
  + 하나의 entry가 하나의 user pool의 physical frame에 대응되어야 한다. 이는 pool이 초기화될 때 각각의 pool에 할당되는 page의 개수만큼 frame table entry를 할당하는 방법으로 구현할 수 있다.
  + 각 frame을 소유하고 있는 프로세스의 정보를 저장해야 한다. 해당 프로세스의 page directory에 접근하여 accessed bit를 참조해 replacement policy를 적용하기 위해서이다.
  + 각 frame을 소유하고 있는 프로세스가 어떤 user virtual page를 해당 frame에 mapping했는지를 저장하여야 한다.

**(2) Frame Table의 설계**

* user pool 초기화 이후 frame table이 초기화되어야 하기 때문에 **“threads/init.c”**의 main()에서 **frame\_init()**을 호출하여 frame 테이블을 초기화하였다.
* frame 테이블의 각 엔트리는 프로세스(쓰레드)에 대한 포인터를 가지고 있고, mapping된 virtual address 정보도 가지고 있다. 각 엔트리는 user page의 physical frame 하나하나에 매칭되고, 엔트리의 인덱스와 frame 주소와의 변환은 **index\_to\_user\_page()**함수를 통해 이루어진다. frame 테이블에는 user pool의 정보만 들어가기 때문에 user pool 비트맵에 접근할 때 사용하였던 수식을 역으로 사용하면 엔트리의 인덱스로 frame의 주소를 접근할 수 있다.
* user pool에 user page가 할당되는 상황은 다음 두 가지 경우가 있다.
  + 프로세스가 load되는 경우: 프로세스가 load되는 모든 상황은 **“threads/process.c”**의 **install\_page()**를 통해 이루어지므로 **install\_page()** 함수 내부에 frame 테이블에 정보를 추가하는 함수인 **add\_frame()**코드를 추가하였다.
  + page가 swap in 되는 경우: swap 기능 구현 참고
* user pool에서 user page가 제거되는 상황은 다음 두 가지 경우가 있다.
  + 프로세스가 종료되는 경우**: process\_exit()** 함수가 호출되는데, 함수 콜 스택 내에 **pagedir\_free\_multiple()** 함수가 호출되기 때문에 수정하지 않아도 된다.
  + page가 swap out 되는 경우: swap 기능 구현 참고
* Frame Table을 구현한 함수들은 **“vm/frame.c”**에 구현되어 있다.

**(3) Frame Table 구현(그림 8–1, 2, 3)**

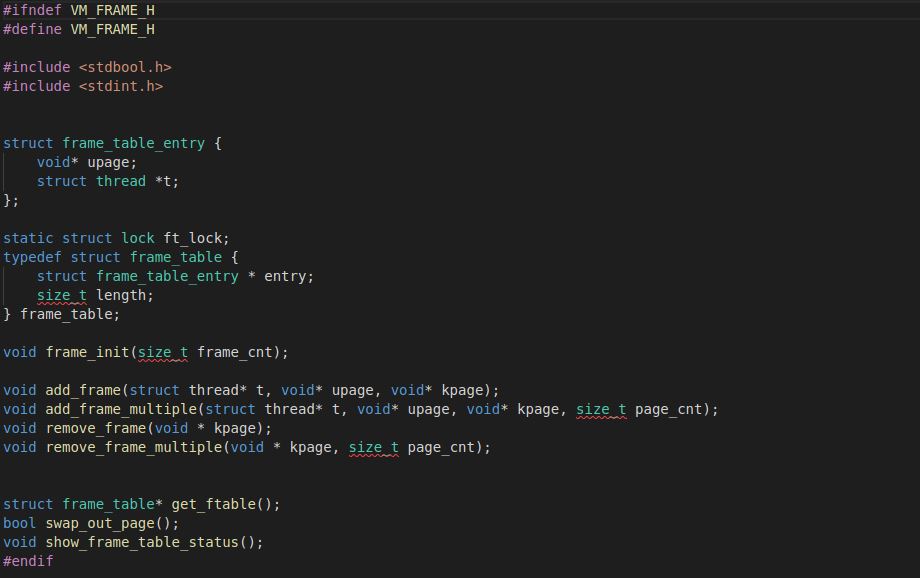


그림 8-1. “vm/frame.h”

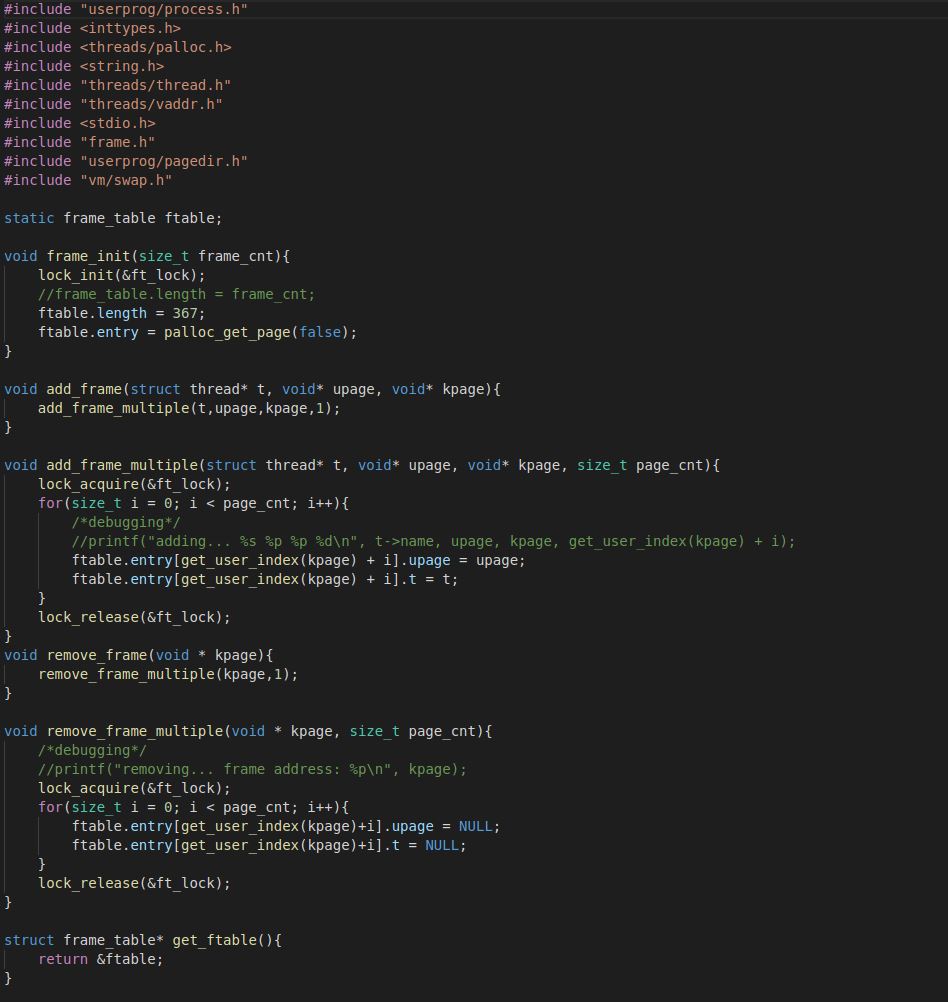


그림 8-2. “vm/frame.c”

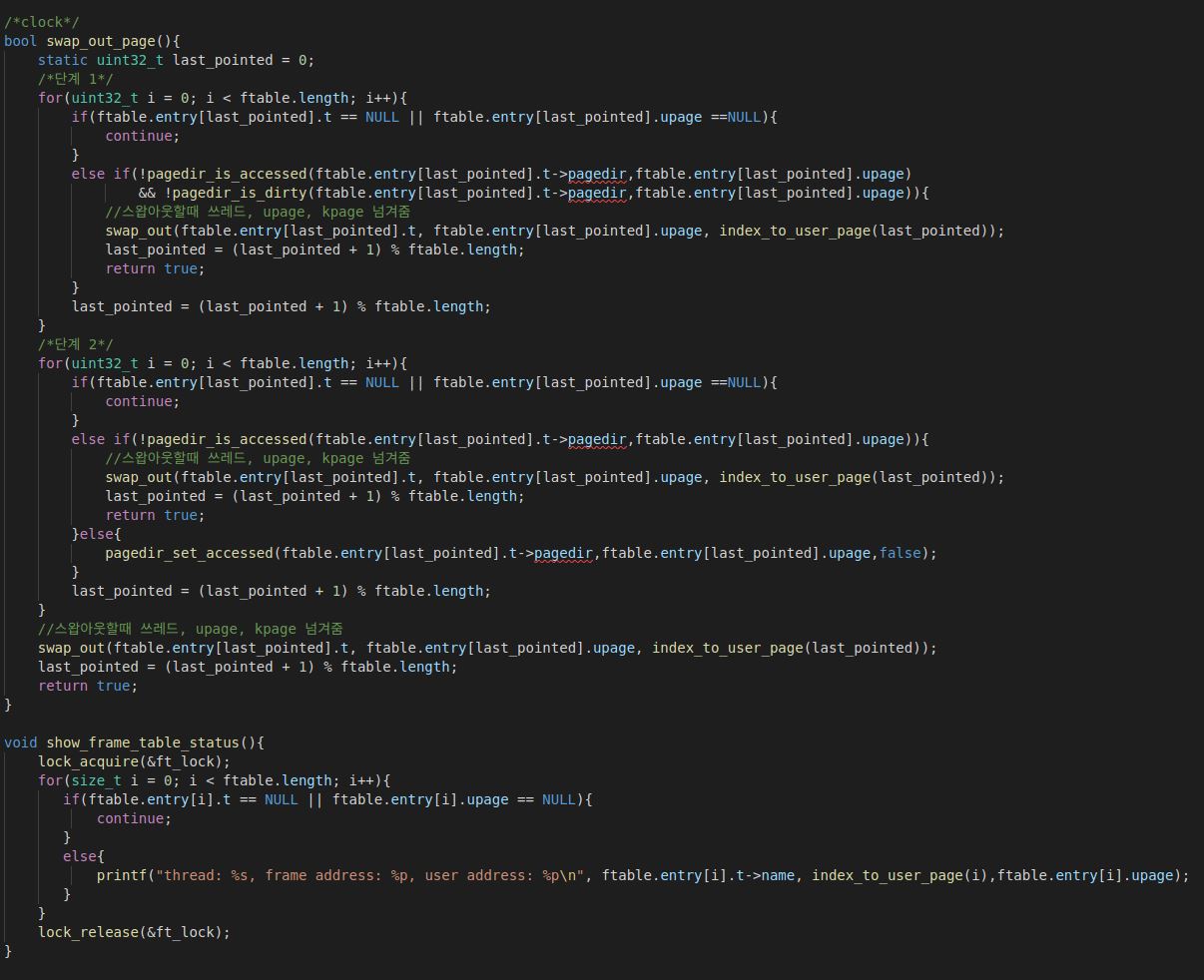


그림 8-3. “vm/frame.c”

**4. 요구사항 4: Page Fault Handler 구현**

**(1) Page Fault Handler 설계**

* 먼저 프로젝트 문서에 정의되지 않은 요소 몇 개를 보면, 한 프로세스당 몇 개의 physical frame을 할당할지에 대한 언급이 없다. 또한 Pintos에서 동시에 여러 user program을 실행시키는 방법도 언급되어 있지 않다.
* 그러한 이유로 한 개의 프로세스가 모든 main memory, swap space를 사용하고, main memory보다 큰 프로세스는 swap space를 이용하여 동작할 수 있게 가상 메모리를 설계하였다. 프로세스가 load될 때 각 page에 메인 메모리의 frame을 하나씩 할당해 주고, 메인 메모리에 공간이 가득 찬 경우는 교체 정책을 이용하여 page를 swap out하고 해당 frame에 page를 할당한다. 따라서 프로세스의 모든 page는 메인 메모리와 swap space에 존재하고, 이 두 공간의 크기보다 큰 frame을 할당해야 하는 프로세스는 load되지 않는다.
* PintOS에서 page Fault가 일어나는 경우는 문서에 제시된 내용을 따랐다.
  + 참조하려는 page가 파일 시스템에 있을 경우: 앞서 언급한 대로 프로세스가 load될 때 모든 page가 main memory, swap space에 올라가기 때문에 일어나지 않는 상황이다. 따라서 이 설계에서는 다루지 않는다.
  + 참조하려는 page가 swap space에 있는 경우: 해당 page가 swap space에 있는지 확인하기 위해서 page fault가 난 쓰레드의 정보를 가져온다. 그 다음 page fault address를 포함하고 있는 page로 주소를 변환하기위해 page offset을 제거하고, 해당 page가 swap space에 있는지 확인하기 위해 **swap\_in()**을 호출한다.

**(2) Page Fault Handler 구현**

**![스크린샷이(가) 표시된 사진

자동 생성된 설명](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDcRXhpZgAATU0AKgAAAAgABAE7AAIAAAAKAAAISodpAAQAAAABAAAIVJydAAEAAAAIAAAQzOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAOq5gOyYge2YhAAABZADAAIAAAAUAAAQopAEAAIAAAAUAAAQtpKRAAIAAAADNjYAAJKSAAIAAAADNjYAAOocAAcAAAgMAAAIlgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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fOAR0NLb6Fpm+KzuZLv7Y9i12XRlEYPll1TGM9AMnPtjvVL/hJrjbM32S08+e3+zS3BVt7pt2/3sA4A5AHStGw1y3t9NEt1NaS3CWklsiiGTz8FSqqW+5tGc5644qJc6T/rv/wDSHs21/Xb/gjbLw1ZNY2bX9ysUl5H5glN5DEsAJIBKOdz9MnGPbNUpbaG+8KrcQRxrc6bL5VwY1A8yJzlHOOpDZXPoVqCHXHSzht7iys7vyAVhedGLRgnOOGAIyScEGmaLqaabfO1xGZbW4iaC4iU4LIw7e4OCPcCm1LV/wBf1bQzbhZW+f8AX4mrpei6RNpuky35vGm1K8e2/cyKqxgFAG5U55fpxn1FVLC4sdIvLi31K1F0YrtOfLVvlRmDDn1449qrQ63cW8OnxRpEV0+4a4iLKcsxKnDc9PkHTHeqVzO11dS3EgAeVy7BegJOeKFGTev9dhKSS03/AOHN7wYovNauNMk/499QtJo3B6AqhdG/BkBrI0q3srrUFi1S++wW5ViZxEZMEKSBtHPJwPbNTaNqq6Q15MsbNcy2zwQMDxGX+Vm/75LAe5p/h3UbPStUa71C0W8VIJBFC8aujSMpVSwPYE59eK1f6f5mf+f+RlUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAbWpabYx+G9N1WwFxGbiSWCaOaRX+dAh3KQq4B39DnGOprFrrL43Wj/Dmws54BE+oXUs5S4hBfywsYR03DKA8/MuCcdSK5Oh7sFsgooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigD/2Q==)**

그림 9. Page Fault Handler(“userprog/exception.c”)

**5. 요구사항 5: Swap 기능 구현**

**(1) Swap에 대한 이해와 분석**

* 메인 메모리로 page를 반입할 때 스왑 공간으로 해당 page의 내용을 옮기기 위해 사용된다. 스왑 공간으로 사용될 디스크는 block 단위로 읽기/쓰기를 할 수 있고, 현재 설정의 Pintos에서는 **“swap.dsk"**를 기본 스왑 공간으로 사용하고 있다. 해당 기능을 제공하는 함수는 **block\_read()**와 **block\_write()**이고, 사용할 block, block의 offset, buffer를 인자로 받는다.
* Pintos에서 page의 크기가 4096 Byte이고, block size가 512 Byte이기 때문에 하나의 page를 swap out 또는 swap in 하기 위해서는 8번의 read/write 함수 호출이 필요하고, 이 횟수는 **“vm/swap.c”**에서 BLOCK\_PER\_PAGE로 계산되어 사용되었다.
* frame table과 비슷하게 swap table을 유지하는 방법이 있다. swap table의 각 인덱스는 swap space의 각 block을 가리키고, 해당 block을 사용하고 있는 page와 쓰레드에 대한 정보를 가지고 있어 swap in 할 때 page directory에 다시 추가할 수 있게 한다.
* page를 swap out하는 함수는 다음과 같이 두 단계로 설계되었다.
  + 어떤 프로세스를 스왑 아웃할지 결정하는 과정

**“vm/frame.c”**에 **swap\_out\_page()**로 선언되어 있다.

replacement policy는 교재 8판 한글 번역서 393페이지에 있는 **“변경 비트를 사용한 클록”**을 사용하였다. 최근 참조여부를 u, 변경여부를 m이라고 하고 참이면 1, 거짓이면 0으로 설정한다고 할 때, 각 frame 분류에 대한 clock 알고리즘은 다음과 같다.

단계 1. 현재 포인터의 위치에서 시작하여, frame buffer들을 scan하되, 그 사용비트 값은 변경하지 않는다. **(u = 0; m = 0)** 상태를 가진 첫 page가 교체 대상으로 선정된다.

단계 2. 단계 1이 실패할 경우, **(u = 0; m = 1)** 상태의 frame을 찾아 다시 scan하되, 지나쳐 가는 모든 frame의 사용 비트를 0으로 설정한다. **(u = 0; m = 1)** 상태의 첫 페이지가 교체 대상이 된다.

단계 3. 단계 2가 실패한 경우, 포인터는 원래의 시작 지점에 위치하게 되고 모든 frame의 사용비트는 0으로 설정된다. 단계 1을 반복하고 필요할 경우 단계 2도 반복하게 되면, 교체 대상이 될 프레임 하나가 찾아진다.

단계 1, 단계 2, 단계 3을 주석으로 구분하였고, 어떤 페이지를 스왑 아웃할지 결정하면 아래의 **swap\_out()**함수를 호출하여 해당 페이지를 스왑 공간으로 옮긴다.

* + 프로세스 t의 페이지 upage가 프레임 주소 kpage에 매핑되었을 때, 해당 페이지를 swap space로 옮기는 과정.

**“vm/swap.c”**에 **swap\_out()**으로 선언되어 있다.

먼저 swap table을 통해 빈 공간이 있는지 살펴본다. 빈 공간이 없는 경우는 프로세스의 크기가 너무 큰 경우로, 해당 프로세스를 종료한다. 공간이 있으면 kpage를 block 단위로 나누어서 **block\_write()**를 호출하며 해당 블록에 쓴다. 다음으로 t의 page directory와 frame, frame table에서 upage를 제거하고, swap table을 업데이트한다.

* page를 swap in하는 함수는 다음과 같이 두 단계로 설계되었다.
  + swap space에 프로세스 t의 페이지 upage가 있을 때, 프레임 주소 kpage에 해당 페이지를 불러오는 과정.

**“vm/swap.c”**에 **swap\_in()**으로 선언되어 있다.

swap table에서 t,upage를 가지고 있는 블록이 있는지 확인한다. 다음으로 kpage에 block offset을 더해 가며 read\_block을 호출해 정확한 위치에 페이지의 내용을 불러온다. 프로세스의 page directory, frame table을 업데이트하고, swap table에서 해당 페이지를 제거한다.

* 스왑 기능이 사용되는 상황은 두 가지 경우가 있다.
  + 프로세스를 loading하는데 메모리 공간이 부족할 때: memory의 공간이 부족하면 replacement policy에 따라 swap out할 page를 선택해 swap out하면 main memory에 남는 공간이 생기기 때문에 그 부분에 페이지를 loading하면 된다.
  + Page fault가 일어나서 swap space에서 해당 page를 불러와야 하는 경우: replacement policy에 따라 swap out할 페이지를 선택해 swap out한 후, page fault를 일으킨 thread, page를 swap table에서 찾아 swap in 한다.
* 추가적으로, 프로세스가 종료될 때 종료된 프로세스가 소유하고 있던 페이지 중 swap space에 할당된 page를 제거해야 하기 때문에 **process\_exit()**에 **swap\_release()** 코드를 추가하였다.

**(2) swap의 구현(그림 10-1, 2, 3, 4)**

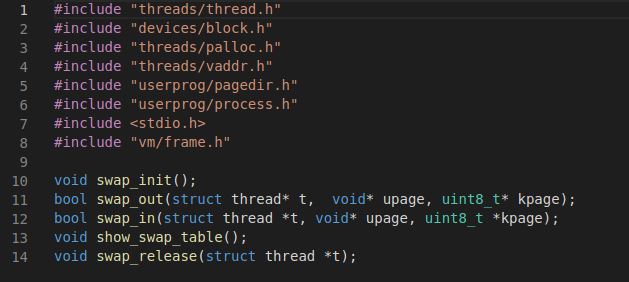


그림 10-1. “vm/swap.h”

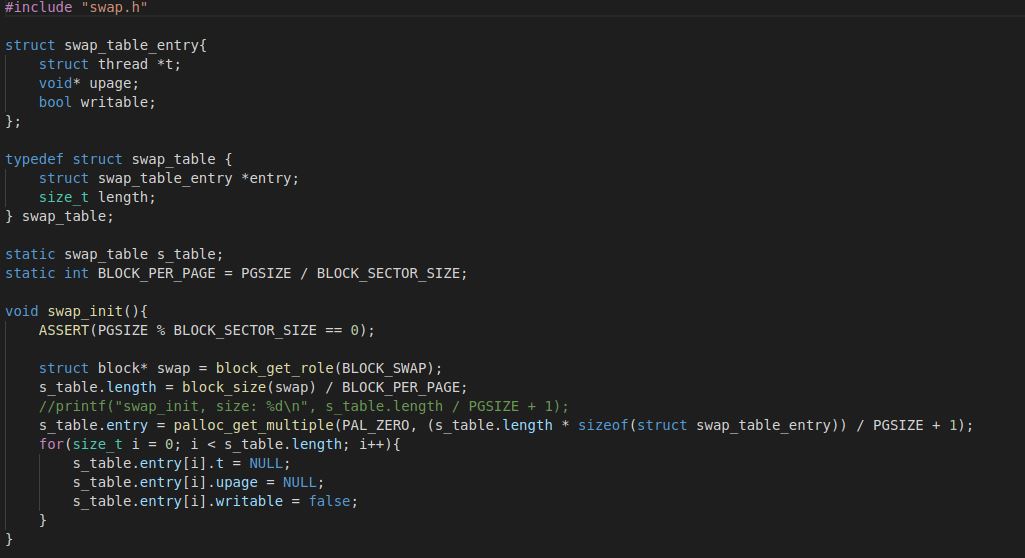


그림 10-2. “vm/swap.c”

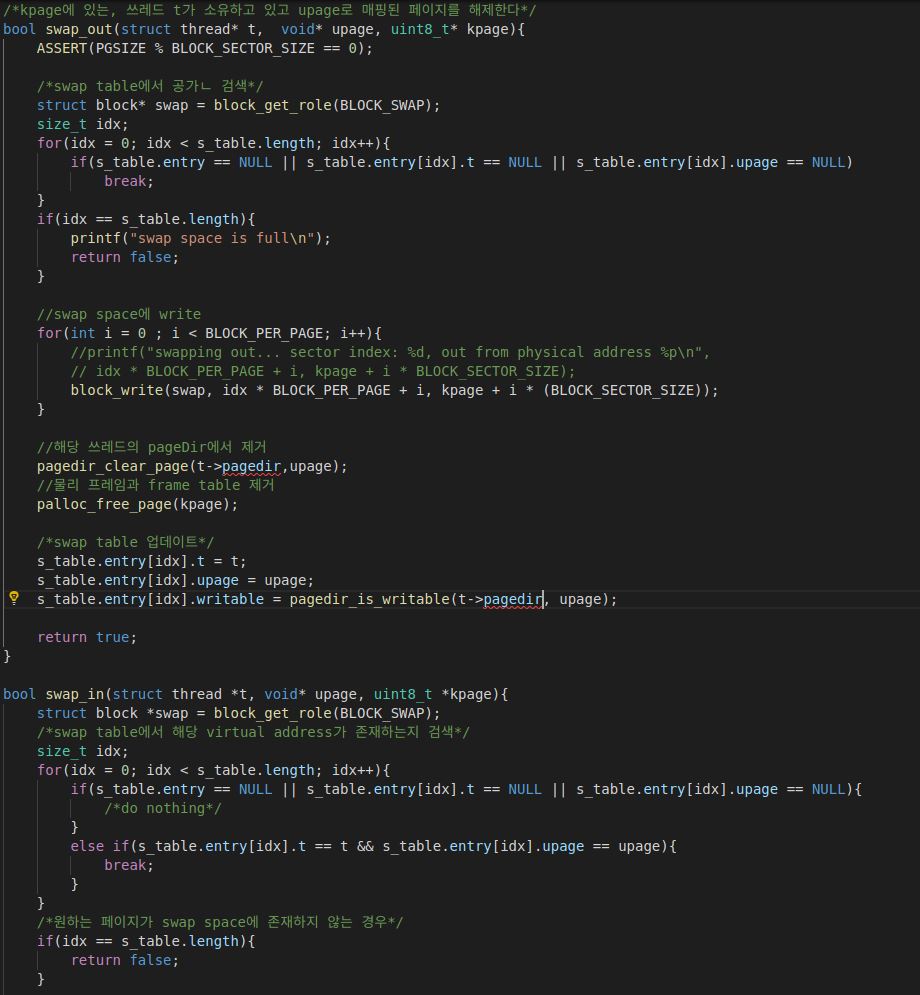


그림 10-3. “vm/swap.c”

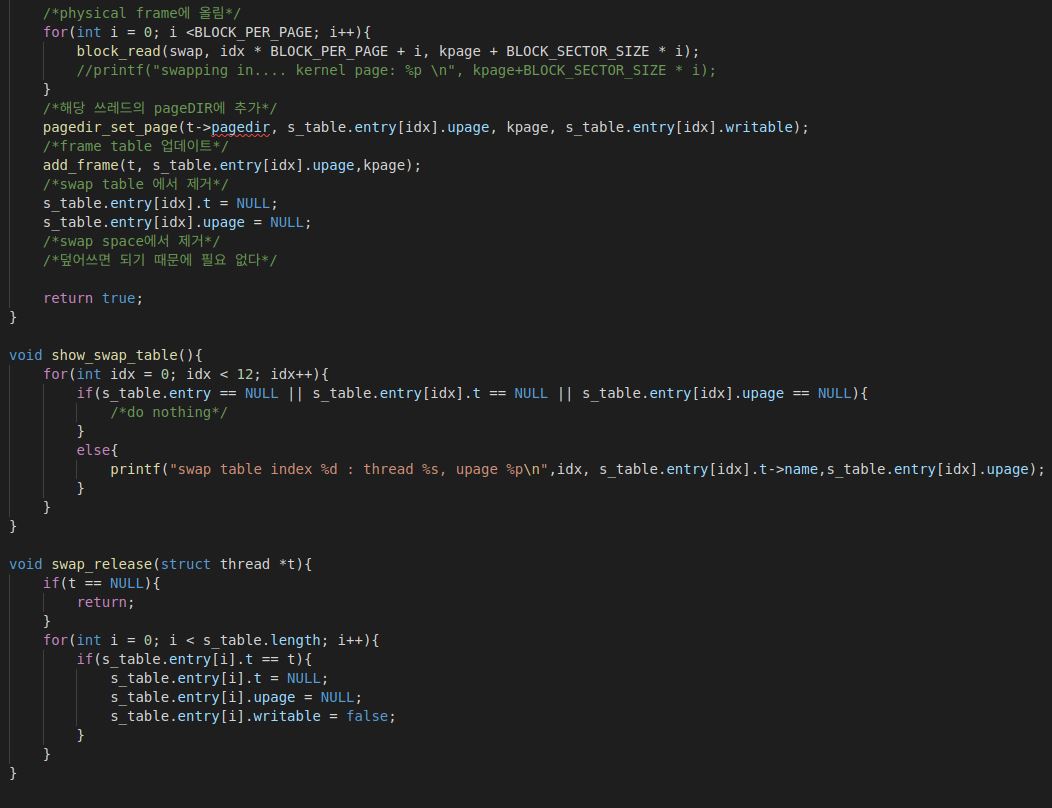


그림 10-4. “vm/swap.c”

**(3) swap 실행 결과: 구현한 Swap replacement policy가 하나밖에 없어서 요구사항 6을 대신하여 첨부.**

* **![텍스트이(가) 표시된 사진

  자동 생성된 설명](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDcRXhpZgAATU0AKgAAAAgABAE7AAIAAAAKAAAISodpAAQAAAABAAAIVJydAAEAAAAIAAAQzOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAOq5gOyYge2YhAAABZADAAIAAAAUAAAQopAEAAIAAAAUAAAQtpKRAAIAAAADMzcAAJKSAAIAAAADMzcAAOocAAcAAAgMAAAIlgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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WqT6mtu6aM1kbTyZC/mCExjkLt2ng5znJ5Heuf1DULefwjo1jFKWmtpbhpY8EbdxXac9DnB6UP4tP61YLZf10/zI4fDGrz6aL6K0zCYzKoMqCR0HVljJ3MoweQMcUxfDupnShqJhjS3ZDIu+4jV3UcFlQtuI4PIFdS3ieGazsrqz1ex06e2sUt2hl0lJZtypt+SXyzww9WGMmqVtqWmP4Z8jWb2zvfLtHjtoPski3UEnJUCQAKUDHPLHjIxQ+tv63BdDDXw7qZ0oaiYY0t2QyLvuI1d1HBZULbiODyBVIWdybJrwQSG2WQRtNsOwMRkLnpnHaupttS0x/DPkaze2d75do8dtB9kkW6gk5KgSABSgY55Y8ZGKwUeP/hGpUOqyrL9qUjTgrbHG0/vc/dyOnrzQ93/AF1BbIzq6eHwektrDEdSC6rcWZvYrLyCVaMAsAZM8MVBIGMe9cxXoVr4uso7S1vW1Iq1vYiJtM8hi0k6xNCjh8YC7Wyec+xofwu2/wDwGC+I49PD2pv5ey2ystsbpX8xdnlDOWLZwMYxgnOeOta8Pg2KSzgDamUv7iwa/jh+zkxeWATgy7uGwp/hxnjNWbfWdKj8Inw017JsuIzcyXm19sU/BEW3GSnygEgfewegq/aeI9Ki0u2jbVSmmppxhn0TyHJln2kFs42cvhtxORjpRLZ2/rf+v+HCO6v/AFt/X/DGLD4PSW1hiOpBdVuLM3sVl5BKtGAWAMmeGKgkDGPelvPCMNj4Zt9VmudQY3Fss6+XppaBSSQEM2/APHp36VtWvi6yjtLW9bUirW9iIm0zyGLSTrE0KOHxgLtbJ5z7GszRb3TtFtZruXXzeGWxeD+zVhlBLOhXaxYbNqk5yCenAol1t/W//ACPS/8AWxVk8I/ZvDq6leT3SySQCdY4LFpI0UjKiSXICkjBxg8EZp0Pg9JbWGI6kF1W4szexWXkEq0YBYAyZ4YqCQMY962IPE+nObDU7jVXU2elGxfSzG5MrCNkGCBs2nIJyc8dKfa+LrKO0tb1tSKtb2IibTPIYtJOsTQo4fGAu1snnPsaJdbf1v8A8AI9L/1t/wAExIfB6S2sMR1ILqtxZm9isvIJVowCwBkzwxUEgYx70Q+D0ltYYjqQXVbizN7FZeQSrRgFgDJnhioJAxj3rbtfF1lHaWt62pFWt7ERNpnkMWknWJoUcPjAXa2Tzn2NFr4uso7S1vW1Iq1vYiJtM8hi0k6xNCjh8YC7Wyec+xol1t/W/wDwP62I9L/1t/wTz2iiigAooooAKKKKACiiigAooooAK1dd0uHTBpvkNI32qxjuX3kHDNnIGB04oooewdTKooooAK1PD2mQ6tqb21y0iottPKDGQDlI2cdQeMgUUUdAMuiiigAooooA1dd0uHTBpvkNI32qxjuX3kHDNnIGB04rKooo6sOgUUUUAdj4G8I2HibT9bnv5bmNtPtjLEIWUBjhj82VPHHbFcdRRQ9wWwUUUUAFFFFABWp4e0yHVtTe2uWkVFtp5QYyAcpGzjqDxkCiijoAeHtMh1bU3trlpFRbaeUGMgHKRs46g8ZArLooo6gFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAVqeHtMh1bU3trlpFRbaeUGMgHKRs46g8ZAooo6AHh7TIdW1N7a5aRUW2nlBjIBykbOOoPGQKy6KKOoBRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFAH//Z)**Page fault를 테스트하기위해 **“examples/echo.c”**에 전역변수로 int array[380000]을 추가하였다.

그림 11-3. Swap 실행 결과

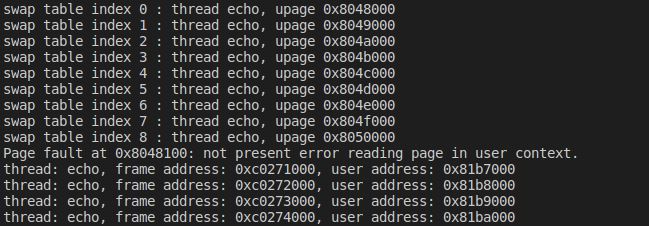


그림 11-2. Swap 실행 결과

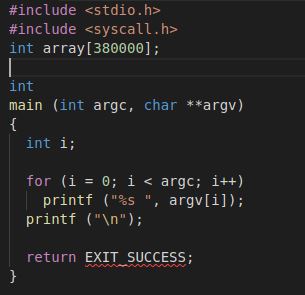


그림 11-1. “examples/echo.c”

**6. 각 팀원이 기여한 사항**

**(1) 20176730 강영빈: 요구사항 1, 3, 4, 5번의 구현**

**(2) 20170937 강제순: 요구사항 3, 4, 5번의 구현**

**(3) 20145822 김영현: 요구사항 1, 2, 3번의 구현, 보고서 작성**