AN914

Dynamic Memory Allocation for the MPLAB® C18 C Compiler

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INTRODUCTION

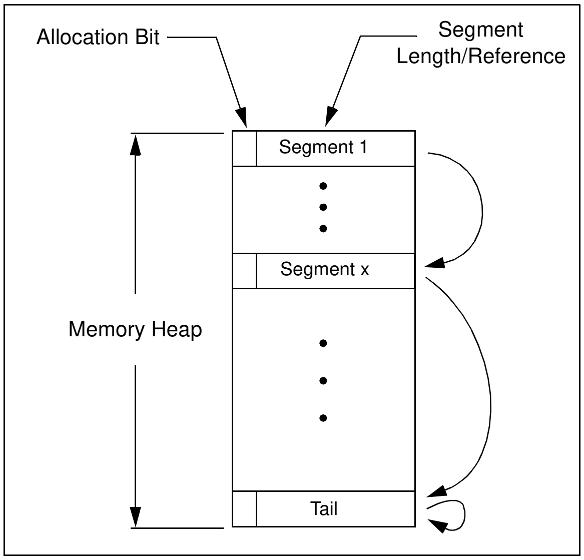
Dynamic memory allocation is a nice functionality that is provided with virtually all PC-based compilers. However, not all microcontroller compilers have such capability, most likely due to the lack of a sophisticated operating system with memory management. Although most applications are static in nature, there are cases where a need for dynamic allocation of memory resources exists. Examples include any number of network protocols that have a dynamically specified nature. This application note presents a simple and efficient method for dynamic memory allocation without the need of an operating system.

THE MODEL

The model is based on a simple form of a linked list. A block of memory referred to as the dynamic heap is split into segments. Each segment has a single-byte header that references the next segment in the list via an offset, as well as indicating whether the segment is allocated. Allocation is specified by a single bit. Figure 1 shows an example. Consequently, the reference implicitly identifies the length of the segment. The heap is terminated with a special header that references itself, referred to as the “tail”.

Why use single-byte headers? The segment headers are specifically designed to be a single byte wide to achieve excellent execution performance, reduce code size and minimize loss of memory space to segment control information. Essentially, one byte references are easier and faster to manipulate than multi-byte relative or absolute references. Plus, they do not consume as much space. However, some fundamental limits are imposed by this methodology. The maximum segment size is 126 bytes, or the size of the heap, whichever is smaller. The smallest segment size is one byte, resulting in a maximum number of segments of one-half of the number of bytes in the heap minus one. For example, in a 512-byte heap, one could expect to dynamically allocate as many as 255 single-byte segments.

FIGURE 1: SIMPLE HEAP EXAMPLE



Although this model will allow dynamic allocation down to a single byte, doing so sacrifices performance and memory. With more segments within the heap, more time is required to attempt to allocate memory. In addition, every segment requires a header byte; therefore, a large number of smaller segments require more memory than a small number of large segments. In the 255-segment example mentioned previously, 50% of the heap is lost to segment header information.

There is also one other potential problem, especially with smaller segments: memory fragmentation. Fragmentation could ultimately doom an application by reducing the largest allocatable block of memory. Thus, dynamic allocation should be restricted to larger blocks to maintain efficiency and effective use of the heap.

Applications that are likely to encounter fragmentation issues should provide a method to handle allocation failures. The implementation depends on the complexity of the application. For some applications, a system Reset may be sufficient. For applications with more advanced memory requirements, it may be necessary to provide allocation management functions. An example might be to force non-critical tasks to give up their memory allocations as needed, then re-allocate memory to them as required.

SUPPORTING FUNCTIONS

There are three functions that manage the heap:

- `SRAMAlloc`: Allocate memory
- `SRAMFree`: Free previously allocated memory
- `SRAMInitHeap`: Initialize the dynamic heap

SRAMAlloc

```
unsigned char * NEAR SRAMAlloc(NEAR unsigned
char nBytes)
```

`SRAMAlloc` is used to allocate a segment of memory within the heap. When it is called, a new segment is created in the heap. Essentially, larger non-allocated segments are split to achieve the requested segment size. If there are a number of smaller non-allocated segments, they will be merged together to create a single larger segment. If a segment of sufficient size cannot be allocated, then an error is returned to the calling application; otherwise, a 16-bit pointer to the segment is returned, which is the next address after the stored segment header. Figure 2 outlines the basic program flow. The application must remember the pointer to successfully free the memory.

SRAMFree

```
void SRAMFree(unsigned char * NEAR pSRAM)
```

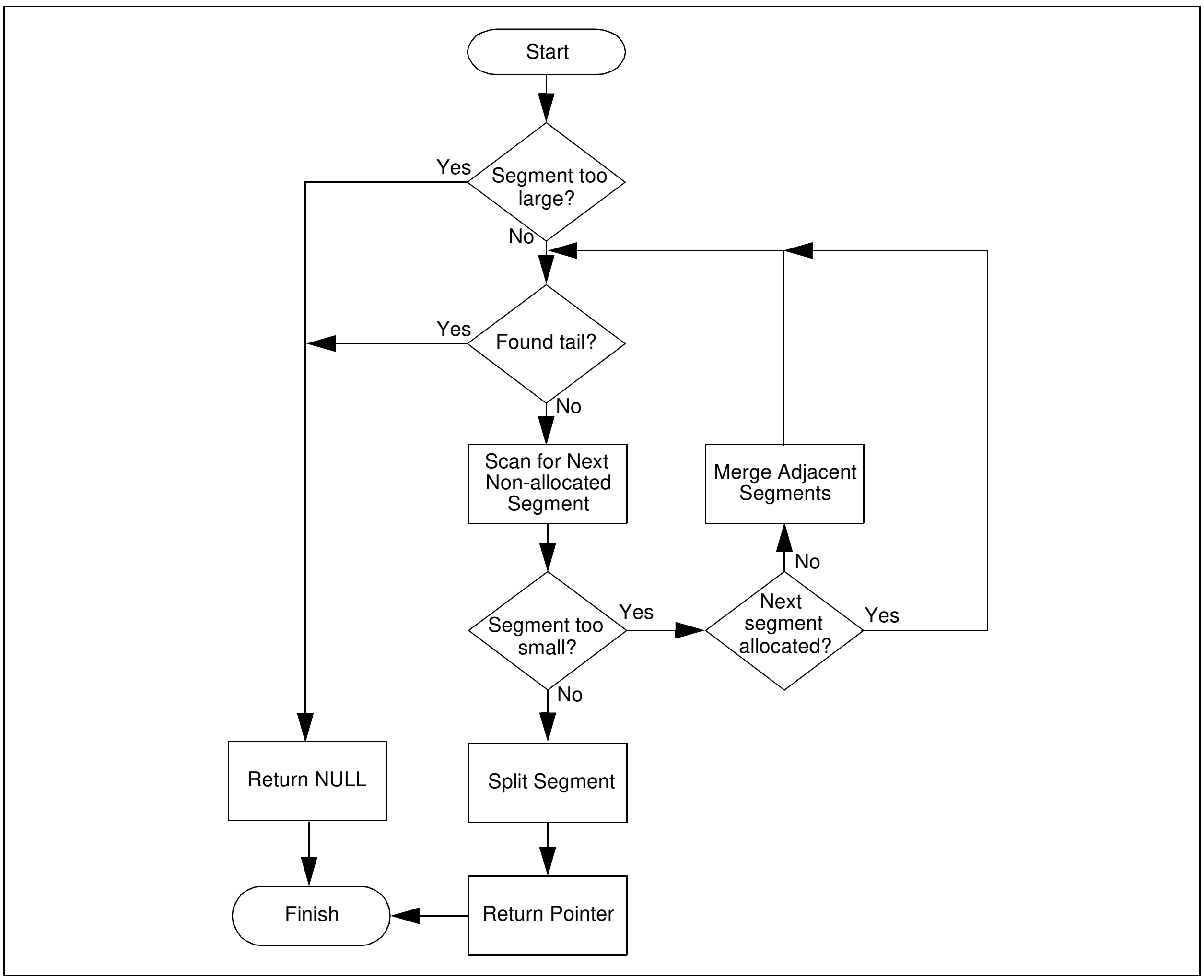
This function is used to free a previously allocated memory segment. It allows future calls to `SRAMAlloc` to merge or split this segment as necessary. The pointer returned from allocation must be passed to successfully free the block of memory.

SRAMInitHeap

```
void SRAMInitHeap(void)
```

This function must be called at least one time to initialize the heap with the minimum number of segment headers and the tail. This function could also be called to initialize the heap. The minimum number is always the value of (`MAX_HEAP_SIZE`/126), rounded up for any remainder. For example, a 256-byte heap will be initialized with three segments.

FIGURE 2: SEGMENT ALLOCATION FLOWCHART



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SETTING UP

Compile Time Options

There are only two compile time options to be set:

- `NEAR_MODEL`: This specifies whether the code uses access registers or normal data space for general processing. There is some small performance improvement using access memory.
- `MAX_HEAP_SIZE`: This specifies the size of the dynamic heap. This value should correlate with the section size specified in the linker script.

The Linker Script

The source code reserves a block of memory specified by a section in the linker file named `_SRAM_ALLOC_HEAP`. Refer to the attached linker script in **Appendix D: "Linker Script"** for an example.

PERFORMANCE

The performance of dynamic allocation varies significantly depending on the build options, the number of segments in the heap, the positions and sizes of the segments and the size of the heap. In the example code, with the build options selected in the example project, allocation can occur in as little as 100 instruction cycles. In other basic tests, with 4 to 5 segments previously allocated, allocation can occur in as much as 450 instruction cycles.

Freeing allocated segments is relatively fixed compared to allocation. In the example code, with the build options selected in the example project, freeing allocated memory only requires 18 instruction cycles.

MEMORY USAGE

The memory usage varies depending on the build options, the number of segments in the heap, the positions and sizes of the segments and the size of the heap. In the example code presented here and with the build options selected in the example project, only 452 bytes of program memory and 20 bytes of data memory are used. In addition, another 512 bytes of data memory are reserved for the dynamic heap. Note that the heap size can be increased or decreased to meet the needs of the application.

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APPENDIX A: ABOUT THE SOURCE CODE

A complete listing of the source code (in C) and the accompanying linker script for the application described here follows in Appendices B, C and D.

The complete code project, including all required linker and header files, is also available from Microchip in electronic format; it may be downloaded from the corporate web site as a Zip archive file. Additionally, this application is included as modular code with Microchip's Application Maestro™ software.

To download the archive, or to get more information on Application Maestro, please visit the Microchip corporate web site at:

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APPENDIX B: MEMORY ALLOCATION SOURCE CODE

```
/*****************************************************************************
 *
 *              Simple SRAM Dynamic Memory Allocation
 *
 *****************************************************************************
 * FileName:        smalloc.c
 * Dependencies:
 * Processor:       PIC18F with CAN
 * Compiler:        C18 02.20.00 or higher
 * Linker:          MPLINK 03.40.00 or higher
 * Company:         Microchip Technology Incorporated
 *
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 *
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 * CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.
 *
 *
 * This is a simple dynamic memory allocation module. The following are the
 * supported services:
 *
 * unsigned char * NEAR SRAMalloc(NEAR unsigned char nBytes)
 * void SRAMfree(unsigned char * NEAR pSRAM)
 * void SRAMInitHeap(void)
 *
 * This version of the dynamic memory allocation limits the segment size
 * to 126 bytes. This is specifically designed such to enable better
 * performance by limiting pointer manipulation.
 *
 *
 * How it works:
 * The model is based on a simple form of a linked list. A block of memory
 * refered to as the dynamic heap is split into segments. Each segment
 * has a single byte header that references the next segment in the list
 * as well as indicating whether the segment is allocated. Consiquently
 * the reference implicitly identifies the length of the segment.
 *
 * This method also enables the possibility of allowing a large number
 * of memory allocations. The maximum is limited by the defined heap size.
 *
 * SRAMalloc() is used to split or merge segments to be allocated.
 * SRAMfree() is used to release segments.
 *
```

```
* Example:
*  ----------
*  |  0x7F  |0x200    Header Seg1
*  |        |
*  |        |
*  |        |
*  |        |
*  |        |
*  |        |
*  |  0x89  |  0x27F  Header Seg2 (allocated)
*  |        |
*  |        |
*  |  0x77  |  0x288  Header Seg3
*  |        |
*  |        |
*  |        |
*  |        |
*  |        |
*  |        |
*  |        |
*  |  0x00  |0x2FF    Tail
*  ----------
*
*
*  Bit 7  Bit 6  Bit 5  Bit 4  Bit 3  Bit 2  Bit 1  Bit 0
*
*  Alloc------------- reference to next Header --------------
*
*
* Recomendations:
* Although this model will allow dynamic allocation down to a single byte,
* doing so sacrifices performance. With more segments within the heap, more
* time is required to attempt to allocate memory. Plus every segment requires
* a header byte; therefore, smaller segments require more memory. There is
* also the possibility of fragmentation, which could ultimately doom an
* application by reducing the largest allocatable block of memory. Thus the
* recomendation is to allocate at least 8 bytes of memory.
*
*
*
* Author             Date           Version    Comment
*~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
* Ross Fosler        05/25/03       v1.03      First release
*
*****************************************************************************/
```

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```
#define NEAR_MODEL
#define MAX_HEAP_SIZE      0x200

#if defined(NEAR_MODEL)
#define NEAR    near
#else
#define NEAR
#endif

#define _MAX_SEGMENT_SIZE  0x7F
#define _MAX_HEAP_SIZE     MAX_HEAP_SIZE-1

/*********************************************************************
 * Segment header data type
 ********************************************************************/
typedef union _SALLOC
{
    unsigned char byte;
    struct _BITS
    {
        unsigned count:7;
        unsigned alloc:1;
    }bits;
}SALLOC;

/*********************************************************************
 * Reserve the memory heap
 ********************************************************************/

#pragma udata_SRAM_ALLOC_HEAP
unsigned char _uDynamicHeap[MAX_HEAP_SIZE];

/*********************************************************************
 * Set the memory type
 ********************************************************************/

#if defined(NEAR_MODEL)
#pragma udata access_SRAM_ALLOC
#else
#pragma udata _SRAM_ALLOC
#endif

/*********************************************************************
 * Private function declarations
 ********************************************************************/

NEAR unsigned char _SRAMmerge(SALLOC * NEAR pSegA);
```

```
/*********************************************************************
 * Function:       unsigned char * SRAMalloc(unsigned char length)
 *
 * PreCondition:   A memory block must be allocated in the linker,
 *                 and the memory headers and tail must already be
 *                 set via the function SRAMInitHeap().
 *
 * Input:          unsigned char nBytes - Number of bytes to allocate.
 *
 * Output:         unsigned char * - A pointer to the requested block
 *                 of memory.
 *
 * Overview:       This functions allocates a chunk of memory from
 *                 the heap. The maximum segment size for this
 *                 version is 126 bytes. If the heap does not have
 *                 an available segment of sufficient size it will
 *                 attempt to create a segment; otherwise a NULL
 *                 pointer is returned. I allocation is succeessful
 *                 then a pointer to the requested block is returned.
 *
 * Note:           The calling function must maintain the pointer
 *                 to correctly free memory at runtime.
 *
 ********************************************************************/

unsigned char * NEAR SRAMalloc(NEAR unsigned char nBytes)
{
    SALLOC * NEAR pHeap;
    SALLOC * NEAR temp;
    NEAR SALLOC segHeader;
    NEAR unsigned char segLen;

    // Do not allow allocation above the max minus one bytes
    if (nBytes > (_MAX_SEGMENT_SIZE - 1)) return (0);

    // Init the pointer to the heap
    pHeap = (SALLOC *)_uDynamicHeap;

    while (1)
    {
        // Get the header of the segment
        segHeader = *pHeap;

        // Extract the segment length from the segment
        segLen = segHeader.bits.count - 1;

        // A null segment indicates the end of the table
        if (segHeader.byte == 0) return (0);

        // If this segment is not allocated then attempt to allocate it
        if (!(segHeader.bits.alloc))
        {
            // If the free segment is too small then attempt to merge
            if (nBytes > segLen)
            {
                // If the merge fails them move on to the next segment
                if (!(_SRAMmerge(pHeap))) pHeap += segHeader.bits.count;
            }
            else
```


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```
            // If the segment length matches the request then allocate the
            // header and return the pointer
            if (nBytes == segLen)
            {
                // Allocate the segment
                (*pHeap).bits.alloc = 1;

                // Return the pointer to the caller
                return ((unsigned char *)(pHeap + 1));
            }

            // Else create a new segment
            else
            {
                // Reset the header to point to a new segment
                (*pHeap).byte = nBytes + 0x81;

                // Remember the pointer to the first segment
                temp = pHeap + 1;

                // Point to the new segment
                pHeap += (nBytes + 1);

                // Insert the header for the new segment
                (*pHeap).byte = segLen - nBytes;

                // Return the pointer to the user
                return ((unsigned char *) temp);
            }
        }

        // else set the pointer to the next segment header in the heap
        else
        {
            pHeap += segHeader.bits.count;
        }
    }
}

/*********************************************************************
 * Function:       void SRAMfree(unsigned char * pSRAM)
 *
 * PreCondition:   The pointer must have been returned from a
 *                 previously allocation via SRAMalloc().
 *
 * Input:          unsigned char * pSRAM - pointer to the allocated
 *
 * Output:         void
 *
 * Overview:       This function de-allocates a previously allocated
 *                 segment of memory.
 *
 * Note:           The pointer must be a valid pointer returned from
 *                 SRAMalloc(); otherwise, the segment may not be
 *                 successfully de-allocated, and the heap may be
 *                 corrupted.
 ********************************************************************/

void SRAMfree(unsigned char * NEAR pSRAM)
{
    // Release the segment
    (*(SALLOC *)(pSRAM - 1)).bits.alloc = 0;
}
```

```
/*********************************************************************
 * Function:       void SRAMInitHeap(void)
 *
 * PreCondition:   none
 *
 * Input:          void
 *
 * Output:         void
 *
 * Overview:       This function initializes the dynamic heap. It
 *                 inserts segment headers to maximize segment space.
 *
 * Note:           This function must be called at least one time.
 *                 And it could be called more times to reset the
 *                 heap.
 ********************************************************************/
void SRAMInitHeap(void)
{
    unsigned char * NEAR pHeap;
    NEAR unsigned int count;

    pHeap = _uDynamicHeap;
    count = _MAX_HEAP_SIZE;

    while (1)
    {
        if (count > _MAX_SEGMENT_SIZE)
        {
            *pHeap = _MAX_SEGMENT_SIZE;
            pHeap += _MAX_SEGMENT_SIZE;
            count = count - _MAX_SEGMENT_SIZE;
        }
        else
        {
            *pHeap = count;
            *(pHeap + count) = 0;
            return;
        }
    }
}

/*********************************************************************
 * Function:       unsigned char _SRAMmerge(SALLOC * NEAR pSegA)
 *
 * PreCondition:   none
 *
 * Input:          SALLOC * NEAR pSegA - pointer to the first segment.
 *
 * Output:         unsigned char - returns the length of the
 *                 merged segment or zero if failed to merge.
 *
 * Overview:       This function tries to merge adjacent segments
 *                 that have not been allocated. The largest possible
 *                 segment is merged if possible.
 ********************************************************************/

NEAR unsigned char _SRAMmerge(SALLOC * NEAR pSegA)
{
    SALLOC * NEAR pSegB;
    NEAR SALLOC uSegA, uSegB, uSum;


    // Init the pointer to the heap
    pSegB = pSegA + (*pSegA).byte;
```


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```
    // Extract the headers for faster processing
    uSegA = *pSegA;
    uSegB = *pSegB;

    // Quit if the tail has been found
    if (uSegB.byte == 0) return (0);

    // If either segment is allocated then do not merge
    if (uSegA.bits.alloc || uSegB.bits.alloc) return (0);

    // If the first segment is max then nothing to merge
    if (uSegA.bits.count == _MAX_SEGMENT_SIZE) return (0);

    // Get the sum of the two segments
    uSum.byte = uSegA.byte + uSegB.byte;


    // If the sum of the two segments are > than the largest segment
    // then create a new segment equal to the max segment size and
    // point to the next segments
    if ((uSum.byte) > _MAX_SEGMENT_SIZE)
    {
        (*pSegA).byte = _MAX_SEGMENT_SIZE;
        pSegA += _MAX_SEGMENT_SIZE; //(*pSeg1).byte;
        pSegB += uSegB.byte; //(*pSeg2).byte ;
        (*pSegA).byte = pSegB - pSegA;

        return (_MAX_SEGMENT_SIZE);
    }
    // Else combine the two segments into one segment and
    // do not adjust the pointers to the next segment
    else
    {
        return ((*pSegA).byte = uSum.byte);
    }
}
```

APPENDIX C: TEST CODE

```
#include "sralloc.h"

void main(void)
{

    unsigned char * pTest1;
    unsigned char * pTest2;
    unsigned char * pTest3;
    unsigned char * pTest4;
    unsigned char * pTest5;
    unsigned char * pTest6;
    unsigned char * pTest7;

    SRAMInitHeap();

    while (1)
    {
        pTest1 = SRAMalloc(1);
        pTest2 = SRAMalloc(126);
        SRAMfree(pTest2);
        SRAMfree(pTest1);

        pTest1 = SRAMalloc(8);
        pTest2 = SRAMalloc(40);
        pTest3 = SRAMalloc(8);
        pTest4 = SRAMalloc(20);
        pTest5 = SRAMalloc(12);
        pTest6 = SRAMalloc(56);
        pTest7 = SRAMalloc(92);

        SRAMfree(pTest2);
        SRAMfree(pTest1);

        pTest1 = SRAMalloc(30);
        pTest2 = SRAMalloc(120);

        SRAMfree(pTest1);
        SRAMfree(pTest4);
        SRAMfree(pTest3);
        SRAMfree(pTest7);
        SRAMfree(pTest6);
        SRAMfree(pTest5);
        SRAMfree(pTest2);
    }

}
```


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APPENDIX D: LINKER SCRIPT

```
// Dynamic Memory Allocation Linker Script Example

LIBPATH  .

FILES c018i.o
FILES clib.lib
FILES p18f458.lib

CODEPAGE NAME=vectors         START=0x0      END=0x29      PROTECTED
CODEPAGE NAME=page            START=0x2A     END=0x7FFF
CODEPAGE NAME=idlocs          START=0x200000 END=0x200007  PROTECTED
CODEPAGE NAME=config          START=0x300000 END=0x30000D  PROTECTED
CODEPAGE NAME=devid           START=0x3FFFFE END=0x3FFFFF  PROTECTED
CODEPAGE NAME=eedata          START=0xF00000 END=0xF000FF  PROTECTED

ACCESSBANK NAME=accessram     START=0x0      END=0x5F
DATABANK NAME=gpr0            START=0x60     END=0xFF
DATABANK NAME=gpr1            START=0x100    END=0x1FF
//DATABANK NAME=gpr2          START=0x200    END=0x2FF
//DATABANK NAME=gpr3          START=0x300    END=0x3FF
DATABANK NAME=gpr4            START=0x400    END=0x4FF
DATABANK NAME=gpr5            START=0x500    END=0x5FF
DATABANK NAME=bankedsfr       START=0xF00    END=0xF5F     PROTECTED
ACCESSBANK NAME=accesssfr     START=0xF60    END=0xFFF     PROTECTED

SECTION NAME=CONFIG    ROM=config

DATABANK NAME=sramalloc       START=0x200    END=0x3FF
SECTION NAME=_SRAM_ALLOC_HEAP RAM=sramalloc

STACK SIZE=0x100       RAM=gpr5
```

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