Standard Librabry

```
#include <...>
```

<stdio.h>

- printf, scanf, fprintf
- fopen, fclose
- puts, -char, getChar

<stdlib.h>

- EXIT_SUCCESS = 0
- EXIT_FAILURE = -1, 1...

<stdint.h>

- int8_t, int16_t, ..., uint8_t, uint16_t, ...

<stddef.h>

- size_t → array size
- ptrdiff_t → pointer size

<stdbool.h>

- bool b = true/false;

<string.h>

- strlen
- strcpy
- strcat
- strcmp

<math.h>

- sqrt

<assert.h>

- assert(boolean expression)

C Snippets

Code Structure

Main

```
int main(void)
{
    ...
    return EXIT_SUCCESS;
}
```

Main with arguments

```
int main(int argc, char *argv[]){
    if (argc < 2) return EXIT_FAILURE;
    while (*argv) {

    }
    return EXIT_SUCCESS;
}
```

Preprocessor

```
#define LENGTH 100
...
int length = LENGTH;

#define SQUARE(x) ((x) * (x))
...
double area = 3.141 * SQUARE(5)

#define DEBUG
...
#if defined DEBUG
#elif ...
#else ..
#endif ...

#ifdef DEBUG
#ifndef DEBUG

#undef DEBUG
```

Header Guard in File name.h

```
#ifndef NAME_H
#define NAME_H
... declarations of name...
#endif

#include "name.h"
```

Conditionals

```
if (...) {

} else if (...) {

} else {

}

int x = a > b ? c : d;

switch(a) {
    case 1:
        ...
        break;
    case 2: case 3:
        ...
```

```
        break;
    default:
        ...
        break;
}

switch(myenum) {
    case ENUMVALUE:
        ...
        break;
    default:
        ...
        break;
}

int cond = 1 < 2; // 1 = true, 0 = false
```

Loops

```
for (int i = 1; i < 5; i++) {

}

while (i < 5) {
    i++;
}

do {

} while (i < 5)
```

Functions

```
int max(int a, int b); // allowed multiple times across files

int max(int a, int b) { // only once
    return a; // arrays cannot be returned
}
...
int m = max(1, 2);

(void) max(1, 2);

int increment(a) {
    return ++a;
}
int a = 1;
increment(a); // a = 1
a = increment(a); // a = 2

int myVoid(void); // parameter check is skipped

void write_int(const int a); // a is read only for this function
```

Dynamic amount of parameters

```
#include <stdarg.h>

void func(unsigned amount, ...) {
```

```
    va_list args;
    va_start(args, amount);
    int value_i = va_arg(args, int);
    va_end(args);
}
```

Bit operations

```
unsigned int number = 0x75;
unsigned int bit = 3; // bit position

// Setting a bit
number |= (1<<bit);

// Clearing a bit
bit = 1;
number &= ~(1<<bit);

// Toggling a bit
bit = 0;
number ^= (1 << bit);

// swap integers
a = a ^ b;
b = a ^ b;
a = a ^ b;

int is_power_of_two(int value) {
    int bits = sizeof(value) * 4;
    int set = 0;
    for (int i=0; i < bits; i++) {
        int mask = (0x01<<i);
        if ((value&mask) == mask) {
              set ++;
        }
        if (set > 1) {
            return EXIT_FAILURE;
        }
    }
    return EXIT_SUCCESS;
}

void print_binary(unsigned int value, int print_new_line) {
    int bits = sizeof(value) * 8 - 1;
    for (int i=bits; i >= 0; i--) {
        int is_set = ((value >> i) & 0x01) == 0x01;
        printf ("%d", is_set >= 1 ? 1 : 0);
        if (i%8 == 0 && i > 0) {
            printf("'");
        }
    }
    if (print_new_line) {
        printf("\n");
    }
}
```

```
/**
 *  Print numbers in various forms
 *
 *  In this version, printbin uses "bitwise and" to test the bits
```

```c
 */
#include <stdio.h>
#include <limits.h>


/**
 *  Print number hexadecimal
 */
void printhex (int num) {
    printf("0x%X", num);
}

/**
 *  Print number decimal
 */
void printnum (int num) {
    printf("%d", num);
}

/**
 *  Print number in binary form
 */
void printbin(int num) {
    unsigned int testBit = INT_MAX + 1u;
    int oneFound = 0;
    int bit;

    while (testBit != 0) {
        bit = (num & testBit) != 0;
        if (oneFound || bit != 0) {
            printf("%d", bit);
            oneFound = 1;
        }
        testBit = testBit >> 1;
    }
}


/**
 *  Demonstrates the print functions
 */
int main (void) {

    printnum(0xCCCCCCCC);
    putchar('\n');

    printhex(0xCCCCCCCC);
    putchar('\n');

    printbin(0xCCCCCCCC);
    putchar('\n');

    printbin(0xCCCC);
    putchar('\n');

    return 0;
}


/**
 *  Print numbers in binary form
 *
```

```c
 *  In this version, printbin uses "bitwise and" to test the bits
 */
#include <stdio.h>
#include <limits.h>


/**
 *  Another function that prints a number in binary form; this variant
 *  demonstrates the use of a configuration parameter for various
 *  settings
 *
 *  @param   num     number to print
 *  @param   config  configuration
 *                   0...31   bit to mark
 *                   +64      mark bit
 *                   +128     print leading zeros
 *                   +256     terminate with linefeed
 */
void printbin2 (int num, int config) {

    //  name configuration bits for better readability
    const int MARK_BIT = 1<<6;
    const int LEADING_ZEROS = 1<<7;
    const int LINEFEED = 1<<8;

    unsigned int testBit = INT_MAX + 1u;
    int oneFound, bit, nBit;

    // if LEADING_ZEROS is set:
    // set oneFound for all bits to be printed
    oneFound = (config & LEADING_ZEROS);

    // if MARK_BIT is set:
    // - mask bit nr to be marked (config & 31)
    // - set bit with this nr (1 << ...)
    // - else nBit is 0: no bits will be marked
    nBit = (config & MARK_BIT) ? 1 << (config & 31) : 0;

    // for all bits
    while (testBit != 0) {
        bit = (num & testBit) != 0;
        if (oneFound || bit != 0) {

            // bit should be marked: print with ()
            if (testBit==nBit) printf("(%d)", bit);

            // else print bit
            else printf("%d", bit);
            oneFound = 1;
        }

        // continue with next bit
        testBit = testBit >> 1;
    }

    // if LINEFEED is set: print a \n character
    if (config & LINEFEED) printf("\n");
}


/**
 *  Demonstrates the print functions
```

```
 */
int main (void) {

    const int MARK  = 1<<6;
    const int ZEROS = 1<<7;
    const int LF    = 1<<8;

    printf("With leading zeros and linefeed:\n");
    printbin2(0xCCCC, LF+ZEROS);

    printf("\nWithout leading zeros:\n");
    printbin2(0xCCCC, LF);

    printf("\nMark bit 3:\n");
    printbin2(0xCCCC, LF+ZEROS+MARK+3);

    int a = 0xcccc0000;
    int b = 0xaaaaaaaa;

    printf("\nBit Operations:\n\n");
    printbin2(a, ZEROS); printf("  0x%X  a\n", a);
    printbin2(b, ZEROS); printf("  0x%X  b\n\n", b);

    printbin2(a & b, ZEROS); printf("  0x%X  a & b\n", a & b);
    printbin2(a | b, ZEROS); printf("  0x%X  a | b\n", a | b);
    printbin2(a ^ b, ZEROS); printf("  0x%X  a ^ b\n\n", a ^ b);

    printbin2(~a, ZEROS); printf("  0x%X  ~a\n", ~a);

    return 0;
}
```

Data Types

Type declarations

```
double a;
int b, c;
int d = 1;
const int e;
bool b;
typedef int f;
f g;
int globalVariable = 1; /* überall sichtbar */
static int globalVariable; /* nur innerhalb datei */
... {
    static int max = 0; /* bei nächstem Funktionsaufruf noch da */
}
auto int a; /* in stack */
register int a; /* in register, tipp zur optimierung */
static int a; /* als 0 initiiert, lebt bis programmende */
extern int a; /* " */
```

Size of Types

- Size of char: 1 bytes
- Size of int: 4 bytes
- Size of short: 2 bytes
- Size of float: 4 bytes

- Size of double: 8 bytes
- Size of pointer: 8 bytes

Type cast

```
int a = 1;
double b = (double) a / 3
```

Enum

```
enum A {a, b, c}; /* 0, 1, 2 */
enum B {a = 1, b, c}; /* b = 2, c = 3 */
enum B {a, b = 2, c}; /* a = 0, c = 3 */
typedef enum {a, b, c} C;
...
int d = a;
int e = b;
enum A f = a;
C g = a;
```

Struct

```
struct a {
    int x;
    int y;
    int z;
};
...
struct a myA = {1, 2, 3};
struct a myB;
myB = myA; /* kopiert */
myB.x = 4;

typedef struct {
    int x;
    int y;
    int z;
} B;
...
B myA = {5, 6, 7}

typedef struct C C;
struct C {
    int x;
    int y;
    int z;
};

void print_struct(const struct a *p) {
    printf("%d", p->x);
}
print_struct(&myA);
```

Booleans

```
#define bool int
#define false 0
#define true 1
```

```
// or
#include <stdbool.h>

bool b1 = true;
bool b2 = false;
```

Second Last Digit

```
int z = 123;
z = (z % 100) - (z % 10)) / 10;
```

Strings

End of string = \0 = 0000000 → Space = Amount of chars + 1

```
char *mystring = "hello";
char mystring[] = "hello";
char mystring[5] = "hello"; // \0 is missing, printf keeps printing until \0
char mystring[6] = "hello";
char mystring[50] = "hello"; // filled up with \0

char mystring[3];
mystring = "hi"; // compile error
mystring[0] = 'h'; // ok
...
mystring[2] = '\0'; // now it is a string

strlen(str); /* 5 */
sizeof(str); /* 6 */

int comparison = strcmp("hans", "haus"); // n < u -> <0

char[] source[10] = "Hellooooo";
char[] dest[10];
char[] mydest = strcpy(dest, source);

char[5] s1 = "hi"; // needs to be large enough
char[3] s2 = "hi";
char[5] myconcatenation = strcat(s1, s2); // "hihi"
```

Uppercase and Lowercase

```
const char toLower(const char c) {
    return c | (1 << 5);
}

const char toUpper(const char c) {
  return c & ~(1 << 5);
}
```

Compare two strings

```
if (strcmp(string1, string2) == 0) {
    // strings are equal
}
```

Integer to string

```
char str[8];
int i = 5;
sprintf(str, "%d",i);
```

String to integer

```
int i = atoi(str);
```

Length of string (pointer)

```
for(i = 0; *(pc + i); i++, len++);
```

Copy string size

```
char origin[] = "...";
char issue = (char*)malloc(sizeof(origin) / sizeof(char) + 1);
```

Iterate tokens

```
char* token = strtok(str, "delimiter");
while (token != NULL) {
    printf(" % s\n", token);
    token = strtok(NULL, " ");
}
```

Edit Tokens

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#define SWAPCHAR(x, y) ((x)^=(y),(y)^=(x),(x)^=(y))
char origin[] = "abcde abcdef abcdefg abcdefgh";

int main(void){
    (void) printf("\n%s", origin);
    char *word = strtok(origin, " ");
    char *issue = NULL;
    issue = (char*)malloc(sizeof(origin) / sizeof(char) + 1);

    while (word != NULL) {
        size_t len = strlen(word);
        if(len == 5) {
            SWAPCHAR(word[1], word[2]);
        } else if(len > 5) {
            SWAPCHAR(word[len - 3], word[len - 2]);
        }
        strcat(issue, word);
        strcat(issue, " ");
        word = strtok(NULL, " ");
    }
    printf("\n\n%s",issue);
    if (issue) free((void *)issue);
    return EXIT_SUCCESS;
}
```

Iterate arguments and swap chars in string

```c
int main(int argc, char *argv[]){
    if (argc < 2) return EXIT_FAILURE;
    int len = 0; char *word; argv++;
    while (*argv) {
        word = *argv;
        len = strlen(word);
        if (len > 4) SWAPCHAR(word[1], word[2]);
        if (len > 5) SWAPCHAR(word[len - 2], word[len - 3]);
        printf("%s ", word);
        argv++;
    }
    return EXIT_SUCCESS;
}
```

IO

Basic Methods

```c
puts("HELLO"); // output
putChar("A");
getchar(); // read one charater

(void) printf("%i", myInt)

int day, month, year;
a = scanf("%d%d%d", &day, &month, &year);
```

Formatting printf

- %d, %i = int
- %u = unsigned int
- %c = char
- %s = string until \0
- %20s = string of 20 chars
- %f = double, float (only printf)
- %e = Scientific notation (mantissa/exponent), lowercase
- %5.4f = 5 lang vor komma, 4 lang nach komma
- %lf = %f für double für scanf
- %g = Use the shortest representation: %e or %f
- %zd = print size_t
- %x, %X unsigned hexadecimal integer 7fa, 7FA
- %o = Unsigned octal
- %% = %
- %a = Hexadecimal floating point, lowercase
- %p = pointer address

Print Dez to Hex

```c
int a = 5;
printf("%x\n", a);
```

User Input with scanf

```c
double my_value = 1;
printf("Enter double value: ");
scanf("%lf", &my_value);

if (scanf("%lf", &my_double) != 1) {
    // invalid, should be the number of converted values
}
scanf("%u", &unsigned_integer);
```

Date input

```c
typedef struct Date {
    int Year;
    int Month;
    int Day;
} date_t;

int main(int argc, const char *argv[]) {
    date_t date;
    if (sscanf(argv[1], "%d-%d-%d", &date.year, &date.month, &date.day) != 3) {
        // invalid
    }
}
```

User Input with getChar

```c
while ((pressedKey = getchar()) != '\n') {
    ...
}
```

Clear Input Buffer

```c
int c;
while((c = getchar()) != '\n' && c != EOF) {}
```

Continue Loop as long as User wants

```c
do {
    int c;
    while((c = getchar()) != '\n' && c != EOF) {}
    printf("Continue? Y/N");
} while(getchar() == 'Y');
```

User Input Integer with validation

```c
int getIntegerValue(const char *text, int min, int max) {
    int wert;
    char eingabe[max];

    while (1) {
        (void) printf("Bitte geben Sie %s ein (%d-%d): ", text, min, max);
        fgets(eingabe, sizeof(eingabe), stdin);

        // Umwandlung in Integer
        wert = atoi(eingabe);

        // Bereichsprüfung
```

```
        if (wert >= min && wert <= max) {
            return wert;
        }
        (void) printf("Ungültige Eingabe. Bitte erneut versuchen.\n");
    }
}

int getIntegerValue(char * str, int min, int max) {
    int value;
    scanf("%s: %d", str, &value);

    if (min < value) {
        min = value;
    }

    if (value > max) {
        max = value;
    }

    return value;
}
```

Print color

```
#define RED   "\x1B[31m"
#define GRN   "\x1B[32m"
#define YEL   "\x1B[33m"
#define WHT   "\x1B[37m"
#define RESET "\x1B[0m"
printf("%s*" RESET, color);
```

Read File with error handling and fgetc

```
#include <stdio.h>
#include <stdlib.h>

void perror_and exit (const char *context) { perror (context); exit(EXIT_FAILURE) ; }

int main (int argc, char *argv[]) {
    if (argc > 1) {
        FILE *f = fopen(argv[1], "rb");
        if (!f) perror_and_exit(argv [1]);
        int line_no = 1;
        int print_line_no = 1;
        int c;
        while((c =fgetc(f)) >= 0) {
            if (print_line_no && printf("%6d ", line_no++) < 0) perror_and_exit ("printf");
            print_line_no = c == '\n';
            if (putchar(c) < 0) perror_and_exit ("putchar");
        }
        if (!feof(f)) PERROR_AND_EXIT("fgetc");
        if (fclose(f) != 0) perror_and_exit("fclose");
        return EXIT_SUCCESS;
    }
    return EXIT_FAILURE;
}
```

Read File with fgets

```
char[] * fgets(buff, n, stream);
FILE *fp;
char filename[] = "person_list.csv";
fp = fopen(filename, "r");
if (fp == NULL) {
    return;
}
char s[128];
list_init();
while(fgets(s, 128, fp) != NULL) {
    person_t* person = malloc(sizeof(person_t));
    person_from_csv_string(person, s);
    list_insert(person);
}
fclose(fp);
```

Write File

```
FILE *fp;
char filename[] = "person_list.csv";
fp = fopen(filename, "w");
if (fp == NULL) {
    perror_and_exit("fopen");
}

person_t* person = list_getFirst();
for(int i = 0; i < list_size(); i++) {
    char s[128];
    if(person_to_csv_string(person, s)){
        fprintf(fp, "%s\n", s); // <-- write
    }
    person = list_getNext();
}

fclose(fp);
```

Serialize with snprintf

```
int snprintf(char * buffer, size_t max_len, const char * format, ... );

snprintf(s,  max_len, "%s,%s,%d", person->name, person->first_name, person->age);
```

Deserialize

```
sscanf(s, "%[^,],%[^,],%d", person->name, person->first_name, &(person->age));
```

Arrays

address of element with index 1 = start address + 1 * sizeof(Element) Bytes

Declarations

```
int data[100] = {0};
data[7] = 20;

int data[5];
data = {1, 2, 3, 4, 5};
```

```c
int data[] = {1, 2, 3, 4, 5}; // length 5

int data[5] = {1, 2, 3, 4}; // data[4] = 0

int b = data[200]; // unchecked
data [300] = 1; // no error on runtime

size_t c = 100;
? s = sizeof(data); // amount of bytes of array
sizeof(*data); // amount of bytes of first element
sizeof(data)/sizeof(*data); // amount of elements

const data[] = {0,1,2,3,4};
data[0] = 1; // compile error
```

Array explicit size

```c
#define N_ENTRIES 100
int array[N_ENTRIES] = {0};
for (size_t i = 0; i < N_ENTRIES; i++) {
    array[i] = ...
}

// END MARKER
#define DATA_SENTRY (-1) // cannot be used elsewhere in array
int array[] = {1, 2, 3, DATA_SENTRY};
for(size_t i = 0; array[i] != DATA_SENTRY; i++) {
    array[i] = ...
}
```

Pass array size

```c
void access(int array[], size_t n) {
    for(size_t i = 0; i < n; i++) {
        array[i] = ...
    }
}
//or
void access(int *array, size_t n) {
    for(size_t i = 0; i < n; i++) {
        array[i] = ...
    }
}

int a[100] = {0};
size_t n = sizeof(a) / sizeof(a[0]); // or n = 100
access(a, n);
```

Immutable start address

```c
int a[3] = {1,2,3};
int b[3] = {1,2,3};
a = b; // compile error
if(a == b) // checks if start address is the same

int *p;
p = a;
p = b;
```

Jagged Array

```
char *jagged = {"two", "three"};
// 0 until jagged[0][2];
// 1 until jagged[1][4];
```

Return array reference

```
int *create_copy(const int array[], int n) { // not int[]
    const int bytes = n * sizeof(int);
    int *cp = malloc(bytes); // not int cp[], would be local variable
    if (cp) memcpy(cp, array, byes);
    return cp;
}
int a[] = {1, 2, 3, 4};
int *copy = create_copy(a, 4);
```

Iterate multidimensional Array

```
for(int row = 0; row < 2; row++) {
    for(int col = 0; col < 3; col++) {
        array[row][col] = ...
    }
}
```

Copy String into Array

```
(void) strcpy(array[i], string);
```

Copy array (b = a)

```
(void) memcpy(b, a, sizeof(a));

for (int i = 0; i < 5; ++i) {
    b[i] = a[i];
}
```

Sort Array of Strings

```
void sortWords(char array[MAX_ROWS+1][MAX_COLUMNS+1], int count) {
    for (int i = 0; i < count - 1; i++) {
        for (int j = 0; j < count - i - 1; j++) {
            if (strcmp(array[j], array[j + 1]) > 0) {
                char temp[MAX_LENGTH + 1];
                (void) strcpy(temp, array[j]);
                (void) strcpy(array[j], array[j + 1]);
                (void) strcpy(array[j + 1], temp);
            }
        }
    }
}
```

Find String in Array

```
int isDuplicate(char array[MAX_WORDS][MAX_LENGTH + 1], size_t n, char *mystring) {
    for (int i = 0; i < n; i++) {
```

```
        if (strcmp(array[i], mystring) == 0) {
            return EXIT_SUCCESS;
        }
    }
    return EXIT_FAILURE;
}
```

Primes from 2 to 100

```
int prim[100], i,j;
for(i = 0; i < 100; i++) prim[i] = i;
for(i = 2; i < 100; i++) {
    if (prim[i]) {
        printf("%d ", prim[i]);
        for (j = 2 * i; j < 100; j += i) {
            prim[j] = 0;
        }
    }
}
```

Pointers

Addition allowed but no substraction, multiplication or division

Pointer declarations

```
int *p;
int* p;
char **ppc; // pointer to pointer to char
char *(*ppc);

char *d[20]; // array of 20 pointers to chars
char **d;
char (*e)[20]; // pointer to array of 20 chars

int * p, q; // p is pointer to int, q is int

int i;
int *ip;
ip = &i; // ip is now address of i
*ip = 3; // i is now 3

int *ip;
*ip = 25; // 25 is written somewhere unknown

p + p[0] - p[2] // string starting from p[2] if p is string
```

Void Pointer

```
int i = 1;
int *ip = &i;
void *vp = ip; // a void pointer can point at anything
int *ip2 = vp; // no casting is needed
```

Const behavior

```
int i;
const int ci;
```

```
int * const ip = &i; // only pointer is const
*ip = 20; // ok
ip = &k; // error

const int * ip = &ci; // only ci ist const
*ip = 20; // error
ip = &k; // ok

cont int * const ip = &ci; // both are const
*ip = 20; // error
ip = &k; // error
```

NULL

```
int *p1 = 0; //ok
int *p2 = NULL; // better
if(p2 == NULL || p2 == 0) ...
```

Pointer on Struct

```
struct student {
char name[30];
};
struct student *sp, s;
(void)strcpy(s.name, "hans");
sp = &s;
(void)printf("%s", (*sp).name);
(void)printf("%s", sp->name);

struct student *sp = malloc(sizeof(struct student));
```

Pointer operations

```
int a[5] = {1, 2, 3, 4, 5}
int *p;

a[3] = 1;
*(a + 3) = 1;
*(p + 3) = 1;
p[3] = 1;

p = a + 3;
p = &a[3];

// p = a+3
*(p + 1) = 17;
p[1] = 17;
a[4] = 17;

p[-1] = 13;
a[2] = 13;

*(p++) = 19;
*p = 19; p++;
a[3] = 19; p = &p[1];

// p = a+4
p -= 2;
```

```
p = &p[-2];
p = &a[2];

if (a < a + 1) // true
if (a > p) // false

p = a; // ok
a = p; // error
```

Iterate array using pointer

```
int a[2];

int *it = a;
for(size_t i = 0; i > 5; i++) {
    *(it + i) = ...
}

for(int *it = a; it != a+5; ++it) {
    *it = ...
}

int *pe = &a[4];
for(int *it = a; it <= pe; it++) {
    *it = ...
}
```

Pass function pointer

```
double sin(double x);
double return_func(int (*func)(double arg), double x) {
    return func(x);
}
double result = return_func(sin, 90.0);
```

Initialize pointer with string / char array

```
char a[] = "hi" // a contains hi
char *pa = "hello"; // pointer to hello on code segment not stack
a = pa; // error
pa = a; // ok, pointer now to a
pa[1] = 'A'; // error, "hello" is immutable
a[1] = 'A'; // ok

int a[] = {1, 2, 3}; // ok
int *pa = {1, 2, 3}; // error
```

Multidimensional array pointer

```
int a[5] = {1, 2, 3, 4, 5};
int *p = a;

int a[2][3] = { {1, 2, 3},{4, 5, 6} };
int (*p)[3] = a;

q[2][3] = 1;
*(*(q + 2) + 3) = 1;
```

Call by reference

```
void swap_int(int *a, int *b) {
    int saved_a = *a;
    *a = *b;
    *b = *a;
}
```

Malloc

Array

```
int *p = malloc(3 * sizeof(int));
if(p == NULL) {
    // error handling
}
p[0] = 1;
...
free(p); // only once! do not reassign to other space before freeing
```

Dynamic data

```
size_t number_of_bytes = get_file_size(my_file);
char *data = malloc(number_of_bytes);
if(!data || read_data(data, my_file) == -1) {
    // error handling
}
process_data(data);
free(data);
```

Linked list

Implementation Link

```
typedef struct node { struct node *next; void *payload; } node_t;

node_t linked_list_append(node_t *root, void *payload) {
    assert(root);
    node_t *p = root;
    while(p->next) p = p->next;
    p->next = malloc(sizeof(node_t));
    if(p->next) {
        *(p->next) = (node_t){ NULL, payload };
    }
    return p->next;
}
```

Threads

Fork

```
pid_t pid;
int status;
pid = fork();
switch (pid) {
  case -1:
    perror("Could not fork");
```

```
    break;
  case 0:
    printf("Child with pid", getpid());
    printf("has Parent    ", getppid());
    break;
  default:
    printf("Parent with pid ", getpid());
    printf("knows child pid", pid);
    wait(&status);
    break;
}
```

Process management

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

#define PERROR_AND_EXIT(M) do { perror(M); exit (EXIT_FAILURE); } while(0)

int main () {
    pid_t cpid = fork();
    if (cpid == -1) PERROR_AND_EXIT("fork");
    if (cpid > 0) {
        // still in parent process
        printf ("Parent: %d forked child %d\n", getpid() , cpid);
        int wstatus;
        // wait blocking for child to terminate
        pid_t wpid = waitpid(cpid, &wstatus, 0);
        if (wpid == -1) PERROR_AND_EXIT ("waitpid");
        printf("Parent: child %d exited with %d (status=0x%x) \n", cpid, WEXITSTATUS(wstatus),
wstatus);
        exit(EXIT_SUCCESS);
    } else {
        // in child process
        printf("Child: %d forked by parent %d\n", getpid(), getppid()) ;
        sleep(3);
        exit(123);
    }
}
```

Load Image

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

#define PERROR_AND_EXIT(M) do { perror(M); exit(EXIT_FAILURE); } while(0)

int main () {
    pid_t cpid = fork();
    if (cpid == -1) PERROR_AND_EXIT("fork");
    if (cpid > 0) {
        // still in parent process
        printf("Parent: %d forked child %d\n", getpid() , cpid);
        int wstatus;
        // wait blocking for child to terminate
        pid_t wpid = waitpid(cpid, &wstatus, 0);
```

```
        if (wpid == -1) PERROR_AND_EXIT ("waitpid");
        printf("Parent: child %d exited with %d (status=0x%x) \n", cpid, WEXITSTATUS (wstatus) ,
wstatus) ;
        exit (EXIT_SUCCESS) ;
    } else {
        // in child process: replace current image by new image
        // argv of the execv image below
        static char *eargv[] = { "ls", "-l", NULL } ;
        if (execv("/bin/ls", eargv) == -1) {
            PERROR_AND_EXIT ("execv: /bin/ls");
        }
        // this line is never reached
    }
}
```

execl / execv

execl(path, ... char arguments)

execv(path, char arguments[])

```
pid_t pid;
int status;
pid = fork();
switch (pid) {
  case -1:
    perror("Could not fork");
    break;
  case 0:
    retval = execl("./ChildProc.e", "ChildProc.e", "argument", NULL);
    if (retval < 0) perror("execl not successful");
    // child process is now replaced
    break;
  default:
    printf("Parent with pid ", getpid());
    printf("knows child pid", pid);
    wait(&status);
    break;
}

// ChildProc.c
int main(int argc, char *argv[]) {
    if (argv[1] == NULL) {
        printf("argument missing\n");
        exit(-1);
    }
}
```

System

Runs program and waits for termination. Returns exit code.

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/wait.h>

#define PERROR_AND_EXIT(M) do { perror(M); exit (EXIT_FAILURE); } while(0)

int main () {
    int ret = system("/bin/ls -1");
```

```
    printf("Exited with %d (status=0x%x) \n", WEXITSTATUS (ret), ret);
    return EXIT_SUCCESS;
}
```

Popen

Allows to read/write stdin and stdout of process.

```
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>

#define PERROR_AND_EXIT(M) do { perror(M); exit(EXIT_FAILURE); } while(0)

int main () {
    FILE *df = popen("df -k --output=pcent . 2>/dev/null", "r") ;
    if (!df) PERROR_AND_EXIT("popen: df -k .");
    char line [BUFSIZ], *end = NULL;
    long int used = -1;
    while (fgets (line, BUFSIZ, df) ) {
        used = strtol(line, &end, 10);
        // line is spaces-number%-newline
        if (end && end != line && *end == '%') break;
        used = -1;
    }
    if (pclose(df)) PERROR_AND_EXIT ("pclose () ");
    if (used < 0 || used > 100) {
        errno = ERANGE;
        PERROR_AND_EXIT ("df -k .");
    }
    char *msg
        = used < 60 ? "Plenty of disk space (%d%% available) \n"
        : used < 80 ? "Maybe some future disk space problems (%d%% available) \n"
        : used < 90 ? "Need to clear out files (%d%% available) \n"
        : "You may face soon some severe disk space problems (%d%% available) \n";
    printf(msg, 100-used);
    return EXIT_SUCCESS;
}
```

Pthread with argument

```
#include <pthread.h>

void *ThreadF(void *argument) {
    charArg =  *(char *)argument;
    ...
    fflush(stdout);
    pthread_exit(0);
}

pthread_t thread1;
char argument;

pthr = pthread_create(&thread1, NULL, ThreadF, (void *)&argument);

if (pthr != 0) perror("Could not create thread");

pthread_join(thread1, NULL);
pthread_join(thread2, NULL);
```

Pthread with return value

```c
#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#include <unistd.h>
#include <pthread.h>

#define PERROR_AND_EXIT(M) do { perror(M); exit(EXIT_FAILURE) ; } while(0)
#define CHECKED_PTHREAD(C) do { int ret = (C); if (ret) { errno = ret; PERROR_AND_EXIT(#C) ; } }
while(0)

void *worker (void *arg) {
    printf("worker\n");
    sleep(3);
    static int ret_value = 123;
    return &ret_value;
}

int main () {
    pthread_t thread;
    CHECKED_PTHREAD(pthread_create(&thread, NULL, worker, NULL));
    printf("main\n");

    static void *retval;
    CHECKED_PTHREAD(pthread_join(thread, &retval));
    printf("worker retval = %d\n", *((int*)retval));

    exit(EXIT_SUCCESS);
}
```

Detach

pthread_detach = Thread resources are freed after it terminates, not after pthread_join. This means there is no return value and you cannot join anymore.

always either join or detach!

Cancel

```c
pthread_cancel(pthread_t thread)
```

Thread ID

```c
thread_t id = pthread_self()
```

Wait

- In parent process before child terminates: blocked until child terminates
- In parent process after child terminates: Child is Zombie until wait was called.
- Parent terminates without waiting for child: Child is orphaned and will be adopted by the first started process.

Signals

Signal	Default Aktion	Beschreibung
SIGINT	Term	Interrupt-Signal von der Tastatur (CTRL-C)

Signal	Default Aktion	Beschreibung
SIGQUIT	Core	Quit-Signal von der Tastatur (CTRL-)
SIGABRT	Core	Abort-Signal via abort () oder assert ()
SIGKILL	Term	Kill-Signal
SIGSEGV	Core	Unzulässiger Speicherzugriff
SIGALRM	Term	Timer-Signal durch alarm () ausgelöst
SIGTERM	Term	Terminierungs-Signal
SIGSTOP	Stop	Stoppt den Prozess (oder ignoriert falls gestoppt)
SIGCONT	Cont	Reaktiviert den Prozess (oder ignoriert falls am Laufen)

sa_flags	Meaning
SA_SIGINFO	sa_sigaction will be handler
0	sa_handler will be handler

Handler	Meaning
SIG_IGN	Ignore
SIG_DFL	Default
handler	Any function

Signal graceful termination

```
#include <sys/types.h>
#include <signal.h>

if (kill(child_pid, SIGTERM) == -1) PERROR_AND_EXIT("kill (SIGTERM)");
```

Signal Handling

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>
#define PERROR_AND_EXIT(M) do { perror(M); exit(EXIT_FAILURE) ; } while(0)
static pid_t start_child(int wait_for_signal) {
    pid_t cpid = fork();
    if (cpid == -1) PERROR_AND_EXIT("fork");
     // the parent returns the child pid
    if (cpid > 0) return cpid;
    // one child waits for a signal (pause() until signal)
    if (wait_for_signal && pause() == -1) PERROR_AND_EXIT("pause");
    // the child exits normally
    exit(123);
}
static void wait_for_child () {
    int wsts;
    pid t wpid = wait(&wsts) ; // wait blocking for any child to terminate
    if (wpid == -1) PERROR_AND_EXIT("wait");
    // WIFEXITED gets exit code
    if (WIFEXITED(wsts)) printf("Child %d: exit=%d (status=0x%04X)\n", wpid, WTERMSIG(wsts) ,
wsts);
    // WIFSIGNALED gets signal value
    if (WIFSIGNALED(wsts)) printf("Child %d: signal=%d (status=0x%04X)\n", wpid, WTERMSIG(wsts) ,
```

```
wsts);
}
int main () {
    // start child that exits with exit code
    pid_t cpid1 = start_child(0);
    // start child that waits for signal to terminate
    pid_t cpid2 = start_child(1);
    printf ("Children started: %d (term with exit), %d (term with signal) \n", cpid1, cpid2);
    // let the children start so that both child processes exist
    sleep (1);
    // tell the child to terminate gracefully
    if (kill(cpid2, SIGTERM) == -1) PERROR_AND_EXIT("kill");
    wait_for_child(); // waits blocking until some child terminates
    wait_for_child(); // waits blocking until some child terminates
}

printf ("Child %d: exit=%d (status=0x%04X) \n", wpid, WEXITSTATUS (wsts) , wsts) ;



}
```

Custom Signal Handler

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>
#include <signal.h>
#define PERROR_AND_EXIT (M) do { perror (M); exit (EXIT_FAILURE) ; } while (0)
static void handler(int sig, siginfo_t *siginfo, void *context) {
    printf("caught (%d): source=%d, this=%d\n", sig, siginfo->si_pid, getpid()) ;
    // raise = send SIGTERM to itself (identical to kill(getpid(), SIGTERM))
    raise(SIGTERM);
}
static void set_handler(int sig, void (*handler) (int, siginfo_t *, void *)) {
    struct sigaction a = { 0 };
    // handler variant with additional signal info signature
    a.sa_flags = SA_SIGINFO;
    // the handler to be registered
    a.sa_sigaction = handler;
    // block all Signals
    if (sigfillset(&a.sa_mask) == -1) PERROR_AND_EXIT ("sigfillset");
    // register handler
    if (sigaction (sig, &a, NULL) == -1) PERROR_AND_EXIT ("sigaction");
}

static void set_default(int sig) {
    struct sigaction a = { 0 };
    a.sa_flags = 0;
    a.sa_handler = SIG_DFL;
    if (sigfillset(&a.sa_mask) == -1) PERROR_AND_EXIT ("sigfillset");
    if (sigaction (sig, &a, NULL) == -1) PERROR_AND_EXIT ("sigaction");
}

static void ignore(int sig) {
    struct sigaction a = { 0 };
    a.sa_flags = 0;
    a.sa_handler = SIG_IGN;
    if (sigfillset(&a.sa_mask) == -1) PERROR_AND_EXIT ("sigfillset");
    if (sigaction (sig, &a, NULL) == -1) PERROR_AND_EXIT ("sigaction");
```

```
}

static pid_t start_child() {
    pid_t cpid = fork();
    if (cpid == -1) PERROR_AND_EXIT("fork");
    if (cpid > 0) return cpid; // parent returns cpid
    set_handler(SIGUSR1, handler) ; // child ...
    if (pause() ==- 1) PERROR_AND_EXIT ("pause");
    exit(EXIT_FAILURE);
}

int main () {
    // start child that waits for signal to terminate
    pid_t cpid = start_child();
    printf("parent=%d, child=%d\n", getpid(), cpid);
    // give time to the child to start
    sleep(1);
    // send signal to child
    if (kill(cpid, SIGUSR1) == -1) PERROR_AND_EXIT ("kill");

    int ws;
    if (wait (&ws) == -1) PERROR_AND_EXIT ("wait");
    if (WIFEXITED (ws)) {
        printf("child exit=%d (status=0x%04X)\n", WEXITSTATUS(ws), ws);
    }
    if (WIFSIGNALED (ws)) {
        printf("child signal=%d (status=0x%04X)\n", WTERMSIG(ws), ws);
    }
}
```

Signal User Interrupt

```
#include <stdio.h> #include <stdlib.h> #include <unistd.h> #include <sys/wait.h> #include
<signal.h> #define PERROR_AND_EXIT(M) do{perror(M);exit(EXIT_FAILURE);} while(0)
void do_work() { for(;;){} }

static void handler(int sig, siginfo_t *siginfo, void *context) {
    printf("User Interrupt\n");
}

int main(void) {
    pid_t cpid = fork();
    if (cpid == -1) {
        PERROR_AND_EXIT("fork");
    }
    if (cpid > 0) {
        // parent will print on user interrupt
        struct sigaction a = { 0 };
        a.sa_flags = SA_SIGINFO;
        a.sa_sigaction = handler;
        if (sigfillset(&a.sa_mask) == -1) {
            PERROR_AND_EXIT("sigfillset");
        } if (sigaction(SIGINT, &a, NULL) == -1) {
            PERROR_AND_EXIT("sigaction");
        }

        do_work();
    } else {
        // child will ignore user interrupt
        struct sigaction a = { 0 };
        a.sa_flags = SA_SIGINFO;
```

```
        a.sa_sigaction = SIG_IGN;
        if (sigfillset(&a.sa_mask) == -1) {
            PERROR_AND_EXIT("sigfillset");
        } if (sigaction(SIGINT, &a, NULL) == -1) {
            PERROR_AND_EXIT("sigaction");
        }

        do_work();
    }
}
```

Pipes

Both ends of the FIFO pipe have their own file descriptor.

- Anonymous: `pipe(int[2]); fork()
- Named: `mkfifo()`

```
#include <sys/types.h>
#include <unistd.h>

int fd[2];
pipe(fd);
pid_t cpid = fork();

if (cpid > 0) {
    // still in parent process: read from pipe
    close (fd[1]) ;
    read(fd [0], ...);
} else {
    // in child process: write to pipe
    close (fd[0]);
    write(fd[1], ...);
}
```

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

#define PERROR_AND_EXIT(M) do { perror(M); exit (EXIT_FAILURE) ; } while(0)
#define MESSAGE "blocking pipe example message ... \n"
#define MSIZE 10

int main () {
    int fd[2];
    if (pipe(fd) ==- 1) PERROR_AND_EXIT ("pipe");
    pid_t cpid = fork();
    if (cpid == -1) PERROR_AND_EXIT("fork");
    if (cpid > 0) {
        // still in parent process: read from pipe
        if (close(fd[1]) ==- 1) PERROR_AND_EXIT ("close");
        int n;
        do {
            char msg [MSIZE];
            n = read(fd[0], msg, MSIZE);
            if (n == -1) PERROR_AND_EXIT("read") ;
            write (STDOUT_FILENO, msg, n) ;
        } while (n>0);
        if (close(fd[0]) == -1) PERROR_AND_EXIT ("close");
```

```
        if (wait(NULL) ==- 1) PERROR_AND_EXIT("wait");
    } else {
        // in child process: write to pipe
        if (close(fd[0]) == -1) {
            PERROR_AND_EXIT ("close");
        }
        if (write(fd[1], MESSAGE, sizeof(MESSAGE)) == -1) {
            PERROR_AND_EXIT ("write");
        }
    }
}
```

Non-Blocking Pipe

```
void set_nonblocking(int fd) {
    int flags = fcntl(fd, F_GETFL, 0) ;
    if (flags == -1) PERROR_AND_EXIT ("fcntl");
    if (fcntl(fd, F_SETFL, flags | O_NONBLOCK) == -1) PERROR_AND_EXIT("fcntl");
}
int pfd[2];
if (pipe(pfd) ==- 1) PERROR_AND_EXIT("pipe");
set_nonblocking(pfd[0]); // set reading file descriptor to non-blocking

...
int n = read(pfd[0], buf, MSGSIZE);
if (n > 0) // use received data
else if (n == 0) // close and stop polling
else if (errno == EAGAIN) // has to wait for poll interval - avoid spin-lock
else // real error
```

Named Pipe

```
#include <sys/types.h
#include <sys/stat.h>
int mkfifo(const char *pathname, mode_t mode);
```

Multiple Readers/Writers

```
#include <sys/types.h>
#include <unistd.h>
#define MSIZE 100

char msg [MSIZE];
struct mq_attr a = { .mq_maxmsg = 10, .mq_msgsize = MSIZE };
q = mq_open("/my-queue", O_CREAT | O_RDWR, 0666, &a) ; // queue name must start on a
pid_t cpid = fork();

if (cpid > 0) {
    // still in parent process: read from queue
    ...
    mq_receive(q, msg, MSIZE, NULL) ;
    ...
    mq_close (q)
} else {
    // in child process: write to queue
    mq_send(q, msg, MSIZE, prio);
    ...
}
```

Posix Queue

```c
#include <mqueue.h>
#include <stdlib.h>
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <sys/wait.h>
#define PERROR_AND_EXIT(M) do { perror(M); exit(EXIT_FAILURE); } while(0)
#define QNAME "/demo" // the name must start on a slash
#define MSIZE 10
int main () {
    int q = 0, cpid = 0, n = 0, wpid = 0;
    struct mq_attr a = { .mq_maxmsg = 10, .mq_msgsize = MSIZE };
    if ((q = mq_open(QNAME, O_CREAT|O_RDWR|O_NONBLOCK|O_EXCL, 0666, &a) ) == -1) {
        PERROR_AND_EXIT("mq_open");
    }
    if ((cpid =fork()) ==- 1) {
        PERROR_AND_EXIT("fork");
    }
    if (cpid > 0) { // parent: shares queue descriptor with child
        if (mq_unlink (QNAME) ==- 1) {
            PERROR_AND_EXIT("mq_unlink"); // remove it from the filesystem again
        }
        // buffer allows for final '\0' to allow interpretation as string
        char msg [MSIZE+1];
        while (wpid == 0) {
            // read messages while the child process has not yet terminated
            // poll interval for non-blocking mq_receive() and non-blocking waitpid()
            sleep(1)
            // read while there are messages
            while ((n = mq_receive(q, msg, MSIZE, NULL) ) > 0) {
                msg[n] ='\0'; // prepare for printf
                printf("Message: '%s'\n", msg);
            }
            if (n == -1 && errno != EAGAIN) {
                PERROR_AND_EXIT ("mq_receive"); // non-blocking read handling
            }
            if ((wpid = waitpid(cpid, NULL, WNOHANG)) == -1) {
                PERROR_AND_EXIT("waitpid"); // non-blocking
            }
        }
        if (mq_close(q) ==- 1) PERROR_AND_EXIT("mq_close"); // close when completed
    } else {
        // child: shares queue descriptor with parent
        if (mq_send(q, "Hello", sizeof("Hello"), 1) ==- 1) {
            PERROR_AND_EXIT("mq_send");
        }
        sleep(2);
        if (mq send(q, "Queue", sizeof ("Queue"), 1) ==- 1) {
            PERROR_AND_EXIT("mq_send");
        }
    }
}
```

Sockets

Unix Domain Socket

```c
#ifndef _DEFS_H_
#define _DEFS_H_
#include <stdio.h>
#include <stdlib.h>
#include <sys/socket.h>
#include <sys/un.h>
#include <unistd.h>
#define SRV_SOCK "/tmp/my-server-socket. sock"
#define CLI_SOCK "/tmp/my-client-socket.sock"
#define BUFFER_SIZE 8192
#define ERR() do { perror(""); exit(1); } while (0)
#endif // _DEFS_H_

// server.c
#include "defs.h"
int main (int argc, const char* argv[]) {
    // server: connection-less UNIX socket
    int fd = socket(AF_UNIX, SOCK_DGRAM, 0);
    if (fd < 0) ERR();
    struct sockaddr_un a = { AF_UNIX, SRV_SOCK };
    unlink(SRV_SOCK) ;
    if (bind(fd, (void*) &a, sizeof(a)) < 0) ERR();
    while (1) {
        char buf[BUFFER_SIZE] = { 0 };
        struct sockaddr_un client = { 0 };
        socklen_t client_len = sizeof(client);
        int n = recvfrom(fd, buf, sizeof(buf), 0,
            (void*) &client, &client_len);

        if (n > 0) printf("%s\n", buf);
        if (n < 0) ERR();
    }
}

}

// client.c
#include "defs.h"
int main(int argc, const char* argv[]) {
    // client: connection-less UNIX socket
    int fd = socket(AF_UNIX, SOCK_DGRAM, 0);
    if (fd < 0) ERR();
    struct sockaddr_un a = { AF_UNIX, CLI_SOCK } ;
    unlink(CLI_SOCK) ;
    if (bind(fd, (void*) &a, sizeof(a))<0) ERR();
    for(int i = 1; i < argc; i++) {
        const char *p = argv[i];
        int len = strlen (p)+  1;
        struct sockaddr_un s = { AF_UNIX, SRV_SOCK } ;
        int n = sendto (fd, p, len, 0,
            (void*) &s, sizeof(s));

        if (n < 0) ERR();
    }
    close(fd);
    unlink(CLIENT);
}
```

TCP Client

```c
int client_connect(const char* ServerName, const char* PortNumber) {
    struct addrinfo hints, *server_info, *p;
    memset(&hints, 0, sizeof(hints));

    hints.ai_family = AF_INET;
    hints.ai_socktype = SOCK_STREAM;

    int status = getaddrinfo(ServerName, PortNumber, &hints, &server_info);

    if (status != 0) {
      ExitOnError(status, "getaddrinfo");
    }

    int sockfd;
    for (p = server_info; p != NULL; p = p->ai_next) {
        if ((sockfd = socket(p->ai_family, p->ai_socktype, p->ai_protocol)) == -1)
        {
             ExitOnError(-2, "socket error");
             continue;
        }
    if (connect(sockfd, p->ai_addr, p->ai_addrlen) == -1) {
        close(sockfd);
        ExitOnError(-3, "connect error");
        continue;
    }
      break; // exit loop if connected successfully
    }

    if (p == NULL) {
        fprintf(stderr, "Could not connect to server\n");
        return -1;
    }

    return sockfd;
}

int receiveResponse(int communicationSocket, char* buffer, int len) {
    int totalReceived = 0;

    while (totalReceived < len) {
        int bytesReceived = recv(
            communicationSocket,
            buffer + totalReceived,
            len - totalReceived,
            RECEIVE_TIMEOUT
        );
        if (bytesReceived == -1) {
            perror("error in recv");
            break;
        }
        totalReceived += bytesReceived;
    }

    return totalReceived;
}

void sendRequest(int communicationSocket, char* buffer, int len) {
    int totalSent = 0;

    while (totalSent < len) {
        int bytesSent = send(
```

```
            communicationSocket,
            buffer + totalSent,
            len - totalSent,
            SEND_TIMEOUT
        );

        if (bytesSent == -1) {
            perror ("Error in send");
            break;
        }
        totalSent += bytesSent;
    }
}
```

TCP Server

```
void server_init(char * portNumber) {
    struct addrinfo hints, *server_info, *p;

    memset(&hints, 0, sizeof(hints));

    hints.ai_family = AF_INET;
    hints.ai_socktype = SOCK_STREAM;

    int status = getaddrinfo(NULL, portNumber, &hints, &server_info);
    if(status != 0){
        ExitOnError(status, "getaddrinfo");
    }

    int sockfd;
    for (p = server_info; p != NULL; p = p->ai_next) {
        if ((sockfd = socket(p->ai_family, p->ai_socktype, p->ai_protocol)) == -1)
        {
             perror("socket error");
             continue;
        }

        if (bind(sockfd, p->ai_addr, p->ai_addrlen) == -1) {
             close(sockfd);
             perror("connect error");
             continue;
        }

        break; // exit when connection successful
    }

    ListeningSocket = sockfd;

    listen(ListeningSocket, MAX_QUEUE);
}

int getRequest(char* requestBuffer, int max_len)
{
    int bytesReceived = recv(
        connectedSocket,
        requestBuffer,
        max_len -1,
        RECEIVE_TIMEOUT
    );
    requestBuffer[bytesReceived] = '\0';
    return bytesReceived;
```

```
}

void sendResponse(char* response, int resp_len) {
    send(connectedSocket, response, resp_len, 0);
}

void server_close_connection(void) {
    close(connectedSocket);
}
```

Synchronisation

Race Condition = The behavior depends on the order that two tasks are done. This can be prevented with

- Blocking
- Signaling
- Waiting
- Temporal exclusive access to a critical section

Mutex

10_SNP_Sys_Thread_Synchronisation-mit-Notizen

```
#include <sys/types.h>
#include <pthread. h>
#include <stdlib.h>
#include <unistd.h>
#include <stdio.h>
#define FATAL(M) do { perror(M); exit(EXIT_FAILURE) ; } while (0)
// for the demo: increases the chance that a context switch happens at an undesired place
#define N 100000000

volatile int value = 0; // shared variable: read and written in both threads
pthread mutex_t mutex;
void * count(void *arg) {
    int delta = *(int*)arg; // increment or decrement (arg is +1 or -1)
    for(int i = 0; i < N; i++) {
        if (pthread_mutex_lock(&mutex) != 0) FATAL("lock");
            int a = value; // read shared variable
            a += delta; // modify
            value = a; // write shared variable
            if (pthread mutex_unlock(&mutex) != 0) FATAL("unlock");
        }
    return NULL;
}

int main (void) {
    if (pthread mutex_init(&mutex, NULL) != 0) FATAL("mutex_init");
    pthread_t th_inc;
    pthread_t th_dec;

    int inc = +1;
    int dec =- 1;
    if (pthread_create(&th_inc, NULL, count, &inc) != 0) FATAL("create") ;
    if (pthread_create(&th_dec, NULL, count, &dec) != 0) FATAL("create");

    if (pthread_join(th_inc, NULL) != 0) FATAL("join");
    if (pthread_join(th_dec, NULL) != 0) FATAL("join");

    // N times increment and N tmies decrement is expected to result in value 0 again
```

```
    if (value != 0) fprintf(stderr, "ERROR: exp-$d, act-%d\n", 0, value);
}
```

Rekursive Locks

```
#include <sys/types.h>
#include <pthread.h>
#include <stdlib.h>
#include <unistd.h>
#include <stdio.h>
#include <errno.h>
#define FATAL(M) do { perror(M); exit(EXIT_FAILURE); } while (0)
#define N 10000000
#define MUTEXATTR PTHREAD_MUTEX_RECURSIVE
pthread_mutexattr_t mutex_attr;
pthread mutex_t mutex;
int value = 0;
void calc(int step) {
    if (pthread_mutex_lock(&mutex) != 0) FATAL("inner lock");
    value += step;
    if (pthread_mutex_unlock (&mutex) != 0) FATAL("inner unlock");
}
void *count(void *p) {
    for(int i= 0; i < N; i++) {
        if (pthread_mutex_lock(&mutex) != 0) FATAL("lock");
        calc(*(int*)p);
        if (pthread_mutex_unlock(&mutex) != 0) FATAL("unlock");
}
int main (void) {
    if (pthread mutexattr_init(&mutex_attr) != 0) {
        FATAL("mutexattr_init");
    }
    if (pthread mutexattr_settype(&mutex_attr, MUTEXATTR) != 0) {
        FATAL("mutexattr_set");
    }
    if (pthread_mutex_init (&mutex, &mutex_attr) != 0) {
        FATAL("mutex_init");
    }
    pthread_t th_inc;
    pthread_t th_dec;
    int inc = +1;
    int dec =- 1;
    if (pthread_create(&th_inc, NULL, count, &inc) != 0) FATAL ("create");
    if (pthread_create(&th_dec, NULL, count, &dec) != 0) FATAL("create");
    if (pthread_join(th_inc, NULL) != 0) FATAL("join");
    if (pthread_join (th_dec, NULL) != 0) FATAL("join");
    if (value != 0) fprintf(stderr, "ERROR: exp=%d, act=%d\n", 0, value);
}
```

Signalization with Semaphores

Unnamed, Between Threads

sem_t sem;	**semaphore instance**
sem_init (&sem, 0, initial_value);	init memory semaphore with initial count
sem_wait (&sem);	wait opertation
sem_post (&sem);	signal operation
sem destroy (&sem);	cleanup

Named, Between Processes

sem_t *sem;	**semaphore instance address**
sem = sem_open("/name", O_CREAT, mode=0700, value);	init IPC semaphore
sem_wait(sem);	wait opertation
sem_post(sem);	signal operation
sem_close(sem);	cleanup
sem_unlink("/name");	remove file

- 0 = tasks wait from beginning
- 1 = 1 tasks can pass
- post = +1
- wait = -1 when available

Unnamed Sephamore

```c
#include <sys/types.h>
#include <pthread.h>
#include <stdlib.h>
#include <unistd.h>
#include <stdio.h>
#include <limits.h>

#include <semaphore.h>

#define FATAL(M) do { perror(M); exit(EXIT_FAILURE); } while(0)
#define CHECK(E,A,M) if((E)==(A));else fprintf(stderr,"ERROR: "M": exp=%d, act=%d\n",E,A)
#define N 10000

volatile int array[N] = { 0 }; // shared variable: init in one thread, then use in both

sem_t sem;

void *min(void *arg) // initialize the data and calculate min value of all
{
    for(int i = 0; i < N; i++) array[i] = i - N/2; // init the shared data -N/2...N-1-N/2
    if (sem_post(&sem) == -1) FATAL("post");

    int value = INT_MAX;
    for(int i = 0; i < N; i++) if (value > array[i]) value = array[i];
    CHECK(-N/2, value, "wrong min value");
    return NULL;
}
void *max(void *arg) // calculate max value of already initialized data
{
    if (sem_wait(&sem) == -1) FATAL("wait");

    int value = INT_MIN;
    for(int i = 0; i < N; i++) if (value < array[i]) value = array[i];
    CHECK(N-1-N/2, value, "wrong max value");
    return NULL;
}

int main(void)
{
    if (sem_init(&sem, 0, 0) == -1) FATAL("sem");
```

```
    pthread_t th_max;
    pthread_t th_min;

    if (pthread_create(&th_max, NULL, max, NULL) != 0) FATAL("create");
    if (pthread_create(&th_min, NULL, min, NULL) != 0) FATAL("create");

    if (pthread_join(th_max, NULL) != 0) FATAL("join");
    if (pthread_join(th_min, NULL) != 0) FATAL("join");
}
```

Named Sephamore

P08 → basicSequence

Action needed 3 Times → Wait 3 Times

Deadlock Conditions

1. In Critical Section
2. Trying to access other critical Section
3. First section is not getting freed
4. Another task has the sections in opposite order

Avoid Deadlock with Fixed Order

```
int first = fromB < toB ? fromB : toB;
int second = fromB > toB ? fromB : toB;
```

Producer-Consumer Problem

Synchronized

```
// Producer
while (1) {
    item = produce_item() ;
    // blocks until space left for item
    sync_insert(sync_fifo, item) ;
}

// Consumer
while (1) {
// blocks until one item available
item = sync_get (sync_fifo) ;
consume_item(item) ;

}
```

Unsynchronized

```
Semaphore space_left = capacity(fifo);
Semaphore space_used = 0;
Mutex mutex;
// Producer
while (1) {
    item = produce_item();
    // blocks until space left for item
    wait(space_left); //block or dec
    lock(mutex);
    insert(fifo, item);
```

```
    unlock(mutex);
    post(space_used); // signal or inc
}
// Consumer
while (1) {
    // blocks until one item available
    wait(space_used); // block or dec
    lock(mutex);
    item = get(fifo);
    unlock(mutex);
    post(space_left); // signal or inc
    consume_item(item);
}
```

Read-Write Problem

Multiple readers allowed but only one writer. Use seperate ReadLock and WriteLock. pthread_rwlock_t

GCC Snippets

gcc -o name name.c → ./name

gcc name.c -o name

gcc -o name main.c other.c

-lm → link libraries like <math.h>

Make Snippets

- `$<` means "the first dependency" (i.e., the `.c` file)
- `$@` would mean "the target" (i.e., the `.o` file)

```
# Default target: builds 'rechner'
all: rechner

# Linking step: combine all .o files into executable
rechner: add.o sub.o mul.o div.o main.o
    gcc -o rechner add.o sub.o mul.o div.o main.o

# Cleanup: remove all .o files and the executable
clean:
    rm -f *.o rechner

# --- Explicit compilation rules for each file ---
# Note: Defines dependencies AND commands for each .o file.
# 'Makefile' is included as a dependency to force recompile
# if the Makefile itself changes (e.g., flags are modified).

add.o: add.c def.h Makefile
    gcc -c add.c

sub.o: sub.c def.h Makefile
    gcc -c sub.c

mul.o: mul.c def.h Makefile
    gcc -c mul.c

div.o: div.c def.h Makefile
    gcc -c div.c
```

```
main.o: main.c def.h Makefile
    gcc -c main.c
```

```
CC = gcc
CFLAGS = -Wall -g
TARGET = program
SOURCES = main.c functions.c
OBJECTS = $(SOURCES:.c=.o)

# Rules
$(TARGET): $(OBJECTS)
    $(CC) -o $(TARGET) $(OBJECTS)

%.o: %.c
    $(CC) $(CFLAGS) -c $<

clean:
    rm -f *.o $(TARGET)
```

PHONY

```
.PHONY default all clean test mytarget
```

Basic Variables

```
TARGET     := bin/triangle
SOURCES    := src/triangle.c src/read.c src/rectang.c
TSTSOURCES := tests/tests.c
LIBS       := -lm
```

Modules

```
TARGET     := bin/tic-tac-toe
MODULES    := src/model.c src/view.c src/control.c
SOURCES    := src/main.c $(MODULES)
TSTSOURCES := tests/tests.c $(MODULES)
```

List from other List (replace a with b)

```
MYFILES := $(SOURCES:%a=%b)
```

Suffix Rule: for .a, generate .b

```
%.b: %.a
    action...
```

Target depending on Lists

```
mytarget: $(MYLIST1) $(MYLIST2)
    echo the target $@ is done
```

Shell Snippets

IO

```
... < file
... > new_file
... 1> new_file
... >> append_to_file
... 2> new_error_file
... >& new_combi_file
... | ... // out to next in
... && ... // only if prev successful
... & // background process
```

Path shortcuts

```
~/ current useres home dir
~name/ names home dir
./ current dir
../ parent dir
* any amount of characters
? one character
[...] one of ...
```

Soft link b referenziert a:

- Verweist auf Pfad der Datei
- Wenn die Zieldatei gelöscht wurde, zeigt der Link ins leere

```
ln -s a b
```

Hard Link

- Verweist direkt auf denselben inode.
- Beide Dateinamen sind gleichwertig (es gibt keine "Originaldatei" mehr)
- Wenn du eine der Dateien löschst, bleibt die andere bestehen, solange noch mindestens ein Hard Link existiert.

```
ln a b
```

ASCII Table

Dez	Hex	Okt	
0	0x00	000	NUL
1	0x01	001	SOH
2	0x02	002	STX
3	0x03	003	ETX
4	0x04	004	EOT
5	0x05	005	ENQ
6	0x06	006	ACK
7	0x07	007	BEL
8	0x08	010	BS
9	0x09	011	TAB
10	0x0A	012	LF
11	0x0B	013	VT
12	0x0C	014	FF
13	0x0D	015	CR
14	0x0E	016	SO
15	0x0F	017	SI
16	0x10	020	DLE
17	0x11	021	DC1
18	0x12	022	DC2
19	0x13	023	DC3
20	0x14	024	DC4
21	0x15	025	NAK
22	0x16	026	SYN
23	0x17	027	ETB
24	0x18	030	CAN
25	0x19	031	EM
26	0x1A	032	SUB
27	0x1B	033	ESC
28	0x1C	034	FS
29	0x1D	035	GS
30	0x1E	036	RS
31	0x1F	037	US

Dez	Hex	Okt	
32	0x20	040	SP
33	0x21	041	!
34	0x22	042	"
35	0x23	043	#
36	0x24	044	$
37	0x25	045	%
38	0x26	046	&
39	0x27	047	'
40	0x28	050	(
41	0x29	051	)
42	0x2A	052	*
43	0x2B	053	+
44	0x2C	054	,
45	0x2D	055	-
46	0x2E	056	.
47	0x2F	057	/
48	0x30	060	0
49	0x31	061	1
50	0x32	062	2
51	0x33	063	3
52	0x34	064	4
53	0x35	065	5
54	0x36	066	6
55	0x37	067	7
56	0x38	070	8
57	0x39	071	9
58	0x3A	072	:
59	0x3B	073	;
60	0x3C	074	<
61	0x3D	075	=
62	0x3E	076	>
63	0x3F	077	?

Dez	Hex	Okt	
64	0x40	100	@
65	0x41	101	A
66	0x42	102	B
67	0x43	103	C
68	0x44	104	D
69	0x45	105	E
70	0x46	106	F
71	0x47	107	G
72	0x48	110	H
73	0x49	111	I
74	0x4A	112	J
75	0x4B	113	K
76	0x4C	114	L
77	0x4D	115	M
78	0x4E	116	N
79	0x4F	117	O
80	0x50	120	P
81	0x51	121	Q
82	0x52	122	R
83	0x53	123	S
84	0x54	124	T
85	0x55	125	U
86	0x56	126	V
87	0x57	127	W
88	0x58	130	X
89	0x59	131	Y
90	0x5A	132	Z
91	0x5B	133	[
92	0x5C	134	\
93	0x5D	135	]
94	0x5E	136	^
95	0x5F	137	_

Dez	Hex	Okt	
96	0x60	140	`
97	0x61	141	a
98	0x62	142	b
99	0x63	143	c
100	0x64	144	d
101	0x65	145	e
102	0x66	146	f
103	0x67	147	g
104	0x68	150	h
105	0x69	151	i
106	0x6A	152	j
107	0x6B	153	k
108	0x6C	154	l
109	0x6D	155	m
110	0x6E	156	n
111	0x6F	157	o
112	0x70	160	p
113	0x71	161	q
114	0x72	162	r
115	0x73	163	s
116	0x74	164	t
117	0x75	165	u
118	0x76	166	v
119	0x77	167	w
120	0x78	170	x
121	0x79	171	y
122	0x7A	172	z
123	0x7B	173	{
124	0x7C	174	|
125	0x7D	175	}
126	0x7E	176	~
127	0x7F	177	DEL