Kódovací příklady

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Přednáška 12

BAB36PRGA – Programování v C

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  Casting Pointer to Array

- Část 2 – Kódovací příklad vícevláknové programování (příklad z 11. přednáška prakticky)

Část I

Část 1 – Kódovací příklady

Obsah

Coding Example – Array and Pointer to Function 1/4

- Implement a program that creates an array of random integer values using `rand()` function from `stdlib.h`. *Fill random function.*
- The integer values are limited to `MAX_NUM` set to, e.g., 20, by `#define MAX_NUM 20`.
- The default number can be adjusted at the compile time – `clang -DLEN=10 program.c`.
- The array is printed to `stdout`. *Print function.*
- The array is sorted using `qsort()` from `stdlib.h`. *Become familiar with* `man qsort`.
- The sorted array is printed to `stdout`.
- The program is then enhanced by processing program arguments to define the no. of values as the first program argument using `atoi()`.

```c
#ifndef LEN
#define LEN 5
#endif

#define MAX_NUM 20

void fill_random(size_t l, int a[l]);
void print(const char *s, size_t l, int a[l]);

int main(void)
{
    int a[LEN]; // allocate the array
    fill_random(LEN, a); // fill the array
    print("Array random: ", LEN, a);
    // TODO call qsort
    print("Array sorted: ", LEN, a);
    return 0;
}
```

Coding Example – Array and Pointer to Function 2/4

```
void fill_random(size_t l, int a[l])
{
   for (size_t i = 0; i < l; ++i) {
      a[i] = rand() % MAX_NUM;
   }
}

void print(const char *s, size_t l, int a[l])
{
   if (s) {
      printf("%s", s);
   }
   for (size_t i = 0; i < l; ++i) {
      printf("%s%d", i > 0 ? " " : "", a[i]);
   }
   putchar('\n');
}
```

- See `man qsort` for `qsort` synopsis.

```
void qsort(
  void *base, size_t nmemb, size_t size,
  int (*compar)(const void *, const void *)
);
```

  - `base` is the pointer to the initial member.
  - `nmemb` is the no. of members.
  - `size` is the size of each member.
  - `compar` is a pointer to the comparision function.

```
int compare(const void *ai, const void *bi)
{
   const int *a = (const int*)ai;
   const int *b = (const int*)bi;
   //ascending
   return *a == *b ? 0 : (*a < *b ? -1 : 1);
}
```

Change the order to descending.

Coding Example – Array and Pointer to Function 3/4

- Use the function name as the pointer to the function.

```
int compare(const void *, const void *);

int main(void)
{
    int a[LEN]; // do not initialize
    fill_random(LEN, a);
    print("Array random: ", LEN, a);
    qsort(a, LEN, sizeof(int), compare);
    print("Array sorted: ", LEN, a);
    return 0;
}
```

- Compile and run if the compilation is successfull using `shell` **logical and** operator `&&`.

```
$ clang sort.c -o sort && ./sort
Array random: 13 17 18 15 12
Array sorted: 12 13 15 17 18
```

- Use compiler flag `-DLEN=10` to define the array length 10.

```
$ clang -DLEN=10 sort.c -o sort && ./sort
Array random: 13 17 18 15 12 3 7 8 18 10
Array sorted: 3 7 8 10 12 13 15 17 18 18
```

Coding Example – Array and Pointer to Function 4/4

- Extend `main()` to pass program arguments.
- Define an error value.

```
enum { ERROR = 100 };

int main(int argc, char *argv[])
{
   const size_t len = argc > 1 ?
      atoi(argv[1]) : LEN;
   if (len > 0) {
      int a[len];
      fill_random(len, a);
      print("Array random: ", len, a);
      qsort(a, len, sizeof(int), compare);
      print("Array sorted: ", len, a);
   }
   return len > 0 ? EXIT_SUCCESS : ERROR;
}
```

- We use the **Variable Length Array** (**VLA**), which length is determined during the runtime.

```
$ clang sort-vla.c -o sort && ./sort
Array random: 13 17 18 15 12 3
Array sorted: 3 12 13 15 17 18

$ clang sort-vla.c -DLEN=7 -o sort && ./sort
Array random: 13 17 18 15 12 3 7
Array sorted: 3 7 12 13 15 17 18

$ clang sort-vla.c -o sort && ./sort 11
Array random: 13 17 18 15 12 3 7 8 18 10 19
Array sorted: 3 7 8 10 12 13 15 17 18 18 19
```

- Be aware the size of the array `a` is limited by the size of the **stack**, see `ulimit -s`.

Obsah

Coding Example – String Sorting 1/5

- Implement a program that sorts program arguments lexicographically using `strcmp` (from `string.h`) and `qsort` (from `stdlib.h`).
- Print the arguments. *Print function.*
- Copy the passed `argv` to newly allocated memory on the heap to avoid changes in `argv`.
  - Exit with -1 if allocation fails. *My malloc function.*
  - Copy strings using `strncpy`. *Copy and copy strings functions.*
- Sort the copied array of strings with the help of `strcmp`. *String compare function.*
- Release the allocated memory. *Release function.*

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

void print(int n, char *strings[n]);

char* copy(const char *str);
char** copy_strings(int n, char *strings[n]);

void* my_malloc(size_t size);
void release(int n, char **strings);

int string_compare(
      const void *p1, const void *p2);

enum { EXIT_OK = 0, EXIT_MEM = -1 };

int main(int argc, char *argv[]);
```

Coding Example – String Sorting 2/5

- Print function directly iterates over strings.

```
void print(int n, char *strings[n])
{
   for (int i = 0; i < n; ++i) {
      printf("%3d. \"%s\"\n", i, strings[i]);
   }
}
```

- Allocate array of pointers to char.

```
char** copy_strings(int n, char *strings[n])
{
   char** ret = my_malloc(n * sizeof(char*));
   for (int i = 0; i < n; ++i) {
      ret[i] = copy(strings[i]);
   }
   return ret;
}
```

We take advantage that the allocation succeeds, or the program terminates with an error.

- Copy call `my_malloc` and use `strncpy`.

```
char* copy(const char *str)
{
   char *ret = NULL;
   if (str) {
      size_t len = strlen(str);
      ret = my_malloc(len + 1);// +1 for '\0'
      strncpy(ret, str, len + 1);//+1 for '\0'
   }
   return ret;
}
```

- The length of the string (by `strlen`) is without the null terminating `'\0'`.
- The copy of the string content needs to include the null terminating character as well.

Coding Example – String Sorting 3/5

- Dynamic allocation calls `malloc` and terminates the program on error.

```
void* my_malloc(size_t size)
{
   void *ret = malloc(size);
   if (!ret) {
      fprintf(stderr,
            "ERROR: Mem allocation error!\n");
      exit(EXIT_MEM);
   }
   return ret;
}
```

- The dynamically allocated array of pointers to (dynamically allocated) strings needs releasing the strings and then the array itself.

```
void release(int n, char **strings)
{
   if (strings && *strings)
      return;

   for (int i = 0; i < n; ++i) {
      if (strings[i]) {
         free(strings[i]); //free string
      }
   }
   free(strings); // free array of pointers
}
```

Coding Example – String Sorting 4/5

- Synopsis of the `qsort` function, see `man qsort`.

```
void qsort(void *base, size_t nmemb, size_t size,
       int (*compar)(const void *, const void *)
      );
```

It passes pointers to the array elements as pointers to constant values.

- We call `qsort` on an array of pointers to strings, which are pointers to char.

```
char **strings = copy_strings(n, argv);
qsort(strings, n, sizeof(char*), string_compare);
```

- We cast the pointer to void as a pointer to pointer to char for accessing the string.

```
int string_compare(const void *p1, const void *p2)
{
   char * const *s1 = p1; // qsort passes a pointer to the array item (string)
   char * const *s2 = p2;
   return strcmp(*s1, *s2);
}
```

Coding Example – String Sorting 5/5

- Call `qsort` on array of pointers.

```
int main(int argc, char *argv[])
{
    int ret = EXIT_OK;
    const int n = argc;
    printf("Arguments:\n");
    print(argc, argv);

    char **strings = copy_strings(n, argv);
    qsort(
          strings, n,
          sizeof(char*), string_compare
         );

    printf("\n Sorted arguments:\n");
    print(n, strings);
    release(n, strings);
    return ret;
}
```

- `clang str_sort.c && ./a.out 4 2 a z c`

```
Arguments:
  0. "./a.out"
  1. "4"
  2. "2"
  3. "a"
  4. "z"
  5. "c"

Sorted arguments:
  0. "./a.out"
  1. "2"
  2. "4"
  3. "a"
  4. "c"
  5. "z"
```

- Further tasks.
  - Implement `strings` as an array of pointers without explicit number of items, but with terminating `NULL` pointer.
  - Implement allocation for strings as a single continuous block of memory storing all the strings separated by `'\0'`.

Obsah

Coding Example – Simple Calculator 1/6

- Implement a calculator that processess an input string containing expression with interger values and operators '+', '-', '*'.

  Sum, sub, and mult functions.

- It reports error and return error values 100 if value is not an interger and 101 in the case of unsupported operator.
- Use pointer to operation functions.
- Process the input step-by-step, avoid reading the whole input, print partial results.
- Handle all possible errors.
  - There must by at least single interger value.
  - If an operator is given, it must be valid and there must be the second operand.
  - If end-of-file (input), and the operator is not given, print the result.

```
enum status { EXIT_OK = 0, ERROR_INPUT = 100,
    ERROR_OPERATOR = 101 };

enum status printe(enum status error);

int main(int argc, char *argv[])
{
   enum status ret = EXIT_OK;
   ...
   return printe(ret);
}

enum status printe(enum status error)
{
   if (error == ERROR_INPUT) {
      fprintf(stderr, "ERROR: Input value\n");
   } else if (error == ERROR_OPERATOR) {
      fprintf(stderr, "ERROR: Operator\n");
   }
   return error;
```

Coding Example – Simple Calculator 2/6

- Implement a calculator that processess an input string containing expression with interger values and operators '+', '-', '*'.

Sum, sub, and mult functions.

- It reports error and return error values 100 if value is not an interger and 101 in the case of unsupported operator.
- Use pointer to operation functions.
- Process the input step-by-step, avoid reading the whole input, print partial results.
- Handle all possible errors.
  - There must by at least single interger value.
  - If an operator is given, it must be valid and there must be the second operand.
  - If end-of-file (input), and the operator is not given, print the result.

```
int sum(int a, int b); // return a + b
int sub(int a, int b); // return a - b
int mult(int a, int b);// return a * b

//define a pointer to a function
typedef int (*ptr)(int, int);

//typedef ptr is needed for the return value
ptr getop(const char *op)
{
   int (*operation)(int, int) = NULL;
   if (op[0] == '+') {
      operation = sum;
   } else if (op[0] == '-') {
      operation = sub;
   } else if (op[0] == '*') {
      operation = mult;
   }
   return operation;
}
```

Coding Example – Simple Calculator 3/6

- Implement a calculator that processess an input string containing expression with interger values and operators '+', '-', '*'.

  Sum, sub, and mult functions.
- It reports error and return error values 100 if value is not an interger and 101 in the case of unsupported operator.
- Use pointer to operation functions.
- Process the input step-by-step, avoid reading the whole input, print partial results.
- Handle all possible errors.
  - There must by at least single interger value.
  - If an operator is given, it must be valid and there must be the second operand.
  - If end-of-file (input), and the operator is not given, print the result.

```
    int r = 1; //the first v1
    char opstr[2] = {}; //store the operator
    ptr op = NULL; // function pointer
    int v2; //store the second operand
    while (r == 1 && ret == EXIT_OK) {
       r = (op = readop(opstr, &ret)) ? 1 : 0;
// operator is valid and second operand read
          int v3 = op(v1, v2);
          printf("%3d %s %3d = %3d\n",
                v1, opstr, v2, v3);
          v1 = v3; //shift the results
       } else if (!op) { // no operator
          printf("Result: %3d\n", v1);
          r = 0;
       } else if (r != 1) { //no operand
          ret = ERROR_INPUT;
       }
    } //end of while
```

Coding Example – Simple Calculator 4/6

- Implement a calculator that processess an input string containing expression with interger values and operators '+', '-', '*'.

Sum, sub, and mult functions.

- It reports error and return error values 100 if value is not an interger and 101 in the case of unsupported operator.
- Use pointer to operation functions.
- Process the input step-by-step, avoid reading the whole input, print partial results.
- Handle all possible errors.
  - There must by at least single interger value.
  - If an operator is given, it must be valid and there must be the second operand.

```
    enum status ret = EXIT_OK;
    int v1;

    int r = scanf("%d", &v1) == 1;
    ret = r == 0 ? ERROR_INPUT : ret;
    if (ret == EXIT_OK) {
       ret = process(ret, v1);
    }
...

ptr readop(char *opstr, enum status *error)
{
    ptr op = NULL; // pointer to a function
    int r = scanf("%1s", opstr);
    if (r == 1) {
       *error = (op = getop(opstr)) ? *error :
     ERROR_OPERATOR;
    } // else end-of-file
    return op;
```

Coding Example – Simple Calculator 5/6

```
enum status process(enum status ret, int v1)
{
   int r = 1; //the first operand is given in v1
   char opstr[2] = {}; //store the operator
   ptr op = NULL; // function pointer to operator
   int v2; //store the second operand
   while (r == 1 && ret == EXIT_OK) {
      r = (op = readop(opstr, &ret)) ? 1 : 0; // operand read succesfully
      if (r == 1 && (r = scanf("%d", &v2)) == 1) { // while ends for r == 0 or r == -1
         int v3 = op(v1, v2);
         printf("%3d %s %3d = %3d\n", v1, opstr, v2, v3);
         v1 = v3; //shift the results
      } else if (!op) { // no operator in the input
         printf("Result: %3d\n", v1); //print the final results
         r = 0;
      } else if (r != 1) { //no operand on the input
         ret = ERROR_INPUT;
      }
   } //end of while
   return ret;
}
```

Coding Example – Simple Calculator 6/6

```
1  enum status { EXIT_OK = 0, ERROR_INPUT = 100,
       ERROR_OPERATOR = 101 };
2  ...
3  typedef int (*ptr)(int, int);
4  ptr getop(const char *op);
5  enum status printe(enum status error);
6  enum status process(enum status ret, int v1);


9  int main(int argc, char *argv[])
10 {
11    enum status ret = EXIT_OK;
12    int v1;

14    int r = scanf("%d", &v1) == 1;
15    ret = r == 1 ? ret : ERROR_INPUT;
16    if (ret == EXIT_OK) {
17       ret = process(ret, v1);
18    }
19    return printe(ret);
20 }
```

- Example of program execution.

```
$ clang calc.c -o calc
$ echo "1 + 2 * 6 - 2 * 3 + 19" | ./calc
  1 +   2 =   3
  3 *   6 =  18
 18 -   2 =  16
 16 *   3 =  48
 48 +  19 =  67
Result:  67

$ echo "1 + 2 *" | ./calc; echo $?
  1 +   2 =   3
ERROR: Input value
100

$echo "1 + 2 a" | ./calc; echo $?
  1 +   2 =   3
Result:   3
ERROR: Operator
```

Obsah

Coding Example – Casting Pointer to Array 1/4

- Allocate array of the size `ROWS` × `COLS` and fill it with random integer values with up to two digits, and print the values are an array.
- Implement fill and print functions.
- Implement print function to print matrix of the size `rows` × `cols`.
- Cast the array of `int` values into `m` - a pointer of arrays of the size `cols`.
- Pass `m` to the function that prints the 2D array (matrix) with `cols` columns.

```c
#define MAX_VALUE 100
#define ROWS 3
#define COLS 4

void fill(int n, int *v);
void print_values(int n, int *a);

int main(int argc, char *argv[])
{
   const int n = ROWS * COLS;
   int array[n];
   int *p = array;

   fill(n, p);
   print_values(n, p);
   return 0;
}
```

Coding Example – Casting Pointer to Array 2/4

- Allocate array of the size `ROWS` × `COLS` and fill it with random integer values with up to two digits, and print the values are an array.
- Implement fill and print functions.
- Implement print function to print matrix of the size `rows` × `cols`.
- Cast the array of `int` values into `m` - a pointer of arrays of the size `cols`.
- Pass `m` to the function that prints the 2D array (matrix) with `cols` columns.

```
void fill(int n, int *v)
{
   for (int i = 0; i < n; ++i) {
      v[i] = rand() % MAX_VALUE;
   }
}

void print_values(int n, int *a)
{
   for (int i = 0; i < n; ++i) {
      printf("%s%i",
        (i > 0 ? " " : ""),
        a[i]
      );
   }
   putchar('\n');
}
```

Coding Example – Casting Pointer to Array 3/4

- Allocate array of the size `ROWS` × `COLS` and fill it with random integer values with up to two digits, and print the values are an array.
- Implement fill and print functions.
- Implement print function to print matrix of the size `rows` × `cols`.
- Cast the array of `int` values into `m` - a pointer of arrays of the size `cols`.
- Pass `m` to the function that prints the 2D array (matrix) with `cols` columns.

```
void print(int rows, int cols, int m[][cols])
{
   for (int r = 0; r < rows; ++r) {
      for (int c = 0; c < cols; ++c) {
         printf("%3i", m[r][c]);
      }
      putchar('\n');
   }
}
```

- The number of columns is mandatory to determine the address of the cell `m[r][c]` in the 2D array (matrix) `m`.
- The pointer `m` can refer to arbitrary number of rows.

Coding Example – Casting Pointer to Array 4/4

- Allocate array of the size `ROWS` × `COLS` and fill it with random integer values with up to two digits, and print the values are an array.
- Implement fill and print functions.
- Implement print function to print matrix of the size `rows` × `cols`.
- Cast the array of `int` values into `m` - a pointer of arrays of the size `cols`.
- Pass `m` to the function that prints the 2D array (matrix) with `cols` columns.

  Try to print the array as matrix with `cols` *columns and* `rows` *columns that is as matrix with* `rows`×`cols` *and* `cols`×`rows`*, respectively.*

```
#define MAX_VALUE 100
#define ROWS 3
#define COLS 4
...
void print(int rows, int cols, int m[][cols]);

int main(int argc, char *argv[])
{
   const int n = ROWS * COLS;
   int array[n];
   int *p = array;

   int (*m)[COLS] = (int(*)[COLS])p;
   printf("\nPrint as matrix %d x %d\n",
          ROWS, COLS);
   print(ROWS, COLS, m);
   return 0;
}
```

Část II

Část 2 – Kódovací příklad vícevláknové programování (příklad z 11. přednáška prakticky)

Vlákna POSIX – Příklad 1/10

- Vytvoření aplikace se třemi aktivními vlákny.
  - Obsluha uživatelského vstupu – funkce `input_thread()`.
    - Uživatel zadá periodu výstupu obnovení stisknutím vyhrazených kláves.
  - Zobrazení výstupu – funkce `output_thread()`.
    - Aktualizce výstupu pouze tehdy, když uživatel interaguje s aplikací nebo když alarm signalizuje, že uplynula perioda.
  - Alarm s periodou definovanou uživatelem – funkce `alarm_thread()`.
    - Obnovení výstupu nebo provedení jiné akce.
- Pro zjednodušení program používá `stdin` a `stdout` s hlášením aktivity vlákna do `stderr`.
- Synchronizační mechanismy jsou demonstrují použití mutexu a podmíněné proměnné.
  - `pthread_mutex_t mtx` – výhradní přístup k `data_t data`;
  - `pthread_cond_t cond` – signalizace vláken.

Sdílená data se skládají z aktuální periody alarmu (`alarm_period`), požadavku na ukončení aplikace (`quit`) a počtu vyvolání alarmu (`alarm_counter`).

Vlákna POSIX – Příklad 2/10

- Včetně hlavičkových souborů, definice datových typů, deklarace globálních proměnných.

```
1  #include <stdio.h>
2  #include <stdlib.h>
3  #include <stdbool.h>
4  #include <termios.h>
5  #include <unistd.h>  // for STDIN_FILENO
6  #include <pthread.h>

8  #define PERIOD_STEP 10
9  #define PERIOD_MAX 2000
10 #define PERIOD_MIN 10

12 typedef struct {
13    int alarm_period;
14    int alarm_counter;
15    bool quit;

17    pthread_mutex_t *mtx; // avoid global variables for mutex and
18    pthread_cond_t *cond; // conditional variable
19 } data_t; // data structure shared among the threads
```

Vlákna POSIX – Příklad 3/10

- Funkce prototypů a inicializace proměnných a struktur.

```
21 void call_termios(int reset); // switch terminal to raw mode
22 void* input_thread(void*);
23 void* output_thread(void*);
24 void* alarm_thread(void*);

26 // - main function -------------------------------
27 int main(int argc, char *argv[])
28 {
29    data_t data = { .alarm_period = 100, .alarm_counter = 0, .quit = false };
30    enum { INPUT, OUTPUT, ALARM, NUM_THREADS }; // named ints for the threads
31    const char *threads_names[] = { "Input", "Output", "Alarm" };
32    void* (*thr_functions[])(void*) = {
33       input_thread, output_thread, alarm_thread // array of thread functions
34    };

36    pthread_t threads[NUM_THREADS]; // array for references to created threads
37    pthread_mutex_t mtx;
38    pthread_cond_t cond;
39    pthread_mutex_init(&mtx, NULL); // initialize mutex with default attributes
40    pthread_cond_init(&cond, NULL); // initialize condition variable with default attributes
41    data.mtx = &mtx;                // make the mutex accessible from the shared data structure
42    data.cond = &cond;              // make the cond accessible from the shared data structure
```

Vlákna POSIX – Příklad 4/10

- Vytvoření vláken a čekání na ukončení všech vláken.

```
43     call_termios(0); // switch terminal to raw mode
44     for (int i = 0; i < NUM_THREADS; ++i) {
45        int r = pthread_create(&threads[i], NULL, thr_functions[i], &data);
46        printf("Create thread '%s' %s\r\n", threads_names[i], ( r == 0 ? "OK" : "FAIL") );
47     }

49     int *ex;
50     for (int i = 0; i < NUM_THREADS; ++i) {
51        printf("Call join to the thread %s\r\n", threads_names[i]);
52        int r = pthread_join(threads[i], (void*)&ex);
53        printf("Joining the thread %s has been %s - exit value %i\r\n", threads_names[i],
       (r == 0 ? "OK" : "FAIL"), *ex);
54     }

56     call_termios(1); // restore terminal settings
57     return EXIT_SUCCESS;
58  }
```

Vlákna POSIX – Příklad 5/10 (Přepnutí terminálu)

- Přepnutí terminálu do režimu *raw*.

```
59 void call_termios(int reset)
60 {
61    static struct termios tio, tioOld; // use static to preserve the initial
       settings
62    tcgetattr(STDIN_FILENO, &tio);
63    if (reset) {
64       tcsetattr(STDIN_FILENO, TCSANOW, &tioOld);
65    } else {
66       tioOld = tio; //backup
67       cfmakeraw(&tio);
68       tcsetattr(STDIN_FILENO, TCSANOW, &tio);
69    }
70 }
```

Volající je zodpovědný za vhodné volání funkce, např. pro zachování původního nastavení musí být funkce volána s argumentem 0 pouze jednou.

Vlákna POSIX – Příklad 6/10 (Vstupní vlákno 1/2)

```
72 void* input_thread(void* d)
73 {
74    data_t *data = (data_t*)d;
75    static int r = 0;
76    int c;
77    while (( c = getchar()) != 'q') {
78       pthread_mutex_lock(data->mtx);
79       int period = data->alarm_period; // save the current period
80       // handle the pressed key detailed in the next slide
   ...
95       if (data->alarm_period != period) { // the period has been changed
96          pthread_cond_signal(data->cond); // signal the output thread to refresh
97       }
98       data->alarm_period = period;
99       pthread_mutex_unlock(data->mtx);
100   }
101   r = 1;
102   pthread_mutex_lock(data->mtx);
103   data->quit = true;
104   pthread_cond_broadcast(data->cond);
105   pthread_mutex_unlock(data->mtx);
106   fprintf(stderr, "Exit input thread %lu\r\n", pthread_self());
107   return &r;
108 }
```

Vlákna POSIX – Příklad 7/10 (Vstupní vlákno 2/2)

- `input_thread()` – zpracuje požadavek uživatele na změnu periody.

```
81 switch(c) {
82    case 'r':
83       period -= PERIOD_STEP;
84       if (period < PERIOD_MIN) {
85          period = PERIOD_MIN;
86       }
87       break;
88    case 'p':
89       period += PERIOD_STEP;
90       if (period > PERIOD_MAX) {
91          period = PERIOD_MAX;
92       }
93       break;
94 }
```

Vlákna POSIX – Příklad 8/10 (výstupní vlákno)

```
96  void* output_thread(void* d)
97  {
98     data_t *data = (data_t*)d;
99     static int r = 0;
100    bool q = false;
101    pthread_mutex_lock(data->mtx);
102    while (!q) {
103       pthread_cond_wait(data->cond, data->mtx); // wait for next event
104       q = data->quit;
105       printf("\rAlarm time: %10i   Alarm counter: %10i", data->alarm_period,
       data->alarm_counter);
106       fflush(stdout);
107    }
108    pthread_mutex_unlock(data->mtx);
109    fprintf(stderr, "Exit output thread %lu\r\n", (unsigned long)pthread_self());
110    return &r;
111 }
```

Vlákna POSIX – Příklad 9/10 (Alarm vlákno)

```
113 void* alarm_thread(void* d)
114 {
115    data_t *data = (data_t*)d;
116    static int r = 0;
117    pthread_mutex_lock(data->mtx);
118    bool q = data->quit;
119    useconds_t period = data->alarm_period * 1000; // alarm_period is in ms
120    pthread_mutex_unlock(data->mtx);

122    while (!q) {
123       usleep(period);
124       pthread_mutex_lock(data->mtx);
125       q = data->quit;
126       data->alarm_counter += 1;
127       period = data->alarm_period * 1000; // update the period is it has been changed
128       pthread_cond_broadcast(data->cond);
129       pthread_mutex_unlock(data->mtx);
130    }
131    fprintf(stderr, "Exit alarm thread %lu\r\n", pthread_self());
132    return &r;
133 }
```

Vlákna POSIX – Příklad 10/10

- Příkladový program `lec11/threads.c` lze zkompilovat a spustit.

```
clang -c threads.c -std=gnu99 -O2 -pedantic -Wall  -o threads.o
clang threads.o -lpthread -o threads
```

- Periodu lze změnit klávesami 'r' a 'p'.
- Aplikace je ukončena po stisknutí 'q'.

```
./threads
Create thread 'Input' OK
Create thread 'Output' OK
Create thread 'Alarm' OK
Call join to the thread Input
Alarm time:        110   Alarm counter:         20Exit input thread 750871808
Alarm time:        110   Alarm counter:         20Exit output thread 750873088
Joining the thread Input has been OK - exit value 1
Call join to the thread Output
Joining the thread Output has been OK - exit value 0
Call join to the thread Alarm
Exit alarm thread 750874368
Joining the thread Alarm has been OK - exit value 0
```

lec11/threads.c

Shrnutí přednášky

Diskutovaná témata

- Kódovací příklady
- Vícevláknové programování