Computer programming

"He who loves practice without theory is like the sailor who boards ship without a ruder and compass and never knows where he may cast."

Leonardo da Vinci

Outline

- File handling
  - High level I/O
    - fopen
    - fclose
    - fread
    - fwrite
    - fsetpos, fgetpos, ftell, fseek
- Applications
  - Combinatorial generation: generating subsets
    - Cross product (Cartesian product)
    - Combinations
    - Permutations
    - Arrangements
    - Power set

High level I/O. Files and Streams

- C views each file as a sequence of bytes
  - File ends with the *end-of-file marker*
    - Or, file ends at a specified byte
- Stream created when a file is opened
  - Provide communication channel between files and programs
  - Opening a file returns a pointer to a **`FILE`** structure
    - Example file pointers:
    - **`stdin`** - standard input (keyboard)
    - **`stdout`** - standard output (screen)
    - **`stderr`** - standard error (screen)
- **`FILE`** structure
  - File descriptor - Index into operating system array called the open file table
  - File Control Block (FCB) - Found in every array element, system uses it to administer the file

Files and Streams

- Read/Write functions in standard library
  - `fgetc` - reads one character from a file
    - Takes a `FILE` pointer as an argument
    - `fgetc( stdin )` equivalent to `getchar()`
  - `fputc` - writes one character to a file
    - Takes a `FILE` pointer and a character to write as an argument
    - `fputc( 'a', stdout )` equivalent to `putchar( 'a' )`
  - `fgets` - read a line from a file
  - `fputs` - write a line to a file
  - `fscanf / fprintf` - file processing equivalents of `scanf` and `printf`

Creating a Sequential Access File

- C imposes no file structure
  - No notion of records in a file
  - Programmer must provide file structure
- Creating a File
  - `FILE *myPtr;` - creates a **`FILE`** pointer
  - `myPtr = fopen("myFile.dat", openmode);`
    - Function `fopen` returns a `FILE` pointer to file specified
    - Takes two arguments - file to open and file open mode
    - If file not opened, `NULL` returned
  - `fprintf` - like `printf`, except first argument is a `FILE` pointer (the file receiving data)
  - `feof(FILE pointer)` - returns `true` if end-of-file indicator (no more data to process) is set for the specified file

Creating a Sequential Access File

- `fclose(FILE pointer)` - closes specified file
  - Performed automatically when program ends
  - Good practice to close files explicitly
- Details
  - Each file must have an unique name and will have a different pointer
    - All file processing must refer to the file using the pointer
  - Each mode can have a 'b' (for binary, e.g. ab, wb, rb+) after mode letter

Mode	Description
r	Open a file for reading.
w	Create a file for writing. If the file already exists, discard the current contents.
a	Append; open or create a file for writing at end of file.
r+	Open a file for update (reading and writing).
w+	Create a file for update. If the file already exists, discard the current contents.
a+	Append; open or create a file for update; writing is done at the end of the file.

Attaching a file to an open stream

- **`freopen(const char *filename, const char *mode, FILE *stream)`**
  - Most common use: associate a file with one of the standard streams
  - Example: cause program begin writing to foo.txt

```
if (freopen("foo.txt", "w", stdout) == NULL)
{
  // error foo.txt cannot be opened
}
```

  - Effect: close any other file previously associated to `stdout` ; then open `foo.txt` and associate it with `stdout`.

Reading Data from a Sequential Access File

- Reading a sequential access file
  - Create a **`FILE`** pointer, link it to the file to read

    ```
    myPtr = fopen( "myFile.dat", "r" );
    ```

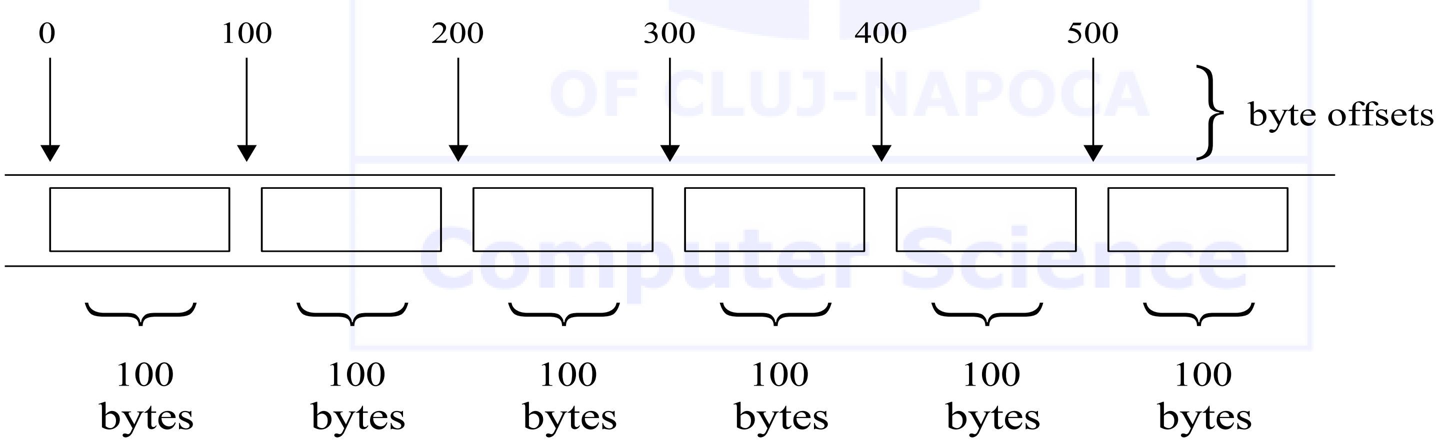
  - Use **`fscanf`** to read from the file
    - Like **`scanf`**, except first argument is a **`FILE`** pointer

```
fscanf( myPtr, "%d%s%f", &myInt, &myString, &myFloat );
```

  - Data read from beginning to end
  - File position pointer - indicates number of next byte to be read/written
    - Not really a pointer, but an integer value (specifies byte location)
    - Also called byte offset
  - **`rewind(myPtr)`** - repositions file position pointer to beginning of the file (byte 0)
  - Cannot be modified without the risk of destroying other data

Random Access Files

- Random access files
  - Access individual records without searching through other records
  - Instant access to records in a file
  - Data can be inserted without destroying other data
  - Data previously stored can be updated or deleted without overwriting.
- Implemented using *fixed length* records
  - Sequential files do not have fixed length records



Creating a Random Access File

- Data
  - Data unformatted (stored as "raw bytes") in random access files
    - All data of the same type (`int`s, for example) use the same memory
    - All records of the same type have a fixed length
    - Data not human readable

Creating a Random Access File

- Unformatted I/O functions
  - **`fwrite`** - Transfer bytes from a location in memory to a file
  - **`fread`** - Transfer bytes from a file to a location in memory
  - **`fwrite( &number, sizeof( int ), 1, myPtr );`**
    - **`&number`** - Location to transfer bytes from
    - **`sizeof( int )`** - Number of bytes to transfer
    - **`1`** - For arrays, number of elements to transfer
      - In this case, "one element" of an array is being transferred
    - **`myPtr`** - File to transfer to or from
    - **`fread`** similar

Writing Data Randomly to a Random Access File

- Writing data: `fwrite`

  ```
  size_t fwrite(const void *ptr, size_t size, size_t
    nelem, FILE *stream);
  ```

  - `ptr` = pointer to memory area where info to write is stored
  - `size` = size in bytes of one element
  - `nelem` = number of elements to write
- E.g. writing `struct`s

  ```
  fwrite( &myObject, sizeof (struct myStruct), 1,
    myPtr );
  ```

  - `sizeof` - Returns size in bytes of object in parentheses
- To write several array elements
  - Pointer to array as first argument
  - Number of elements to write as third argument

Reading Data Sequentially from a Random Access File. Removing a file

- Reading data: `fread`

```
size_t fread(void *ptr, size_t size, size_t nelem,
FILE *stream);
```

  - `ptr` = pointer to memory area where read info will be stored
  - `size` = size in bytes of one element
  - `nelem` = number of elements to write
  - Example:

```
fread( &client, sizeof (struct clientData), 1, myPtr );
```

  - Can read several fixed-size array elements
    - Provide pointer to array
    - Indicate number of elements to read
  - To read multiple elements, specify in third argument
- Removing a file

```
int unlink(const char *path_to_file)
```

  - returns 0 if successful, and -1 on error

File position

```
/* return file position indicator */
long ftell(FILE *stream);
int fgetpos(FILE *stream, fpos_t *pos);
/* set file position indicator to zero */
void rewind(FILE *stream);
/* set file position indicator */
int fseek(FILE *stream, long offset, int ptrname);
int fsetpos(FILE *stream, const fpos_t *pos);
```

- `ftell` returns the current value (measured in characters) of the file position indicator if stream refers to a binary file.
  - For a text file, a 'magic' number is returned, which may only be used on a subsequent call to `fseek` to reposition to the current file position indicator.
  - On failure, `-1L` is returned and `errno` is set.
- `rewind` sets the current file position indicator to the start of the file indicated by stream. The file's error indicator is reset by a call of rewind. No value is returned.

File position

- `fseek` allows the file position indicator for stream to be set to an arbitrary value (for binary files), or for text files, only to a position obtained from `ftell`, as follows:
  - For both functions, on success, zero is returned; on failure, non-zero is returned and `errno` is set.
  - In the general case, the file position indicator is set to offset bytes (characters) from a point in the file determined by the value of ptrname. Offset may be negative. The values of `ptrname` may be `SEEK_SET`, `SEEK_CUR`, and `SEEK_END`. The latter is not necessarily guaranteed to work properly on binary streams.
  - For text files, offset must either be zero or a value returned from a previous call to ftell for the same stream, and the value of `ptrname` must be `SEEK_SET`.
  - `fseek` clears the end of file indicator for the given stream and erases the memory of any `ungetc`. It works for both input and output.
  - Zero is returned for success, non-zero for a forbidden request.

File position

- For `ftell` and `fseek` it must be possible to encode the value of the file position indicator into a `long`. This may not work for very long files, so the Standard introduces `fgetpos` and `fsetpos` which have been specified in a way that removes the problem.
- `fgetpos` stores the current file position indicator for stream in the object pointed to by pos. The value stored is 'magic' and only used to return to the specified position for the same stream using `fsetpos`.
- `fsetpos` works as described above, also clearing the stream's end-of-file indicator and forgetting the effects of any `ungetc` operations.

Example: text file

```
#include <stdio.h>
#include <stdlib.h>
int main(int argc, char *argv[])
{
    char ch, s[100], filename[]="textfile.txt";
    int i;
    FILE *fp;
    /* create file */
    fp = fopen(filename, "w");
    printf("\nInput lines of text for file. End with Ctrl/Z\n");
    while ((ch = getc(stdin)) != EOF) putc(ch, fp);
    fclose(fp);
    /* add text to file */
    fp = fopen(filename, "r+");
    fseek(fp, 0l, SEEK_END);
    printf("\nInput lines text to add to file. End with Ctrl/Z\n");
    while (fgets(s, sizeof(s), stdin) != NULL) fputs(s, fp);
    fclose(fp);
    /* display contents */
    printf("\nLines of the file (numbered):\n");
    i=1;
    fp = fopen(filename, "r");
    while (fgets(s, sizeof(s), fp) != NULL) printf("%d: %s", i++, s);
    fclose(fp);
  system("PAUSE");
  return 0;
}
```

Cross product

- Consider *n* sets of positive integers: $A_1, A_2, \ldots, A_n$.
  - Set A_i , for $i=1, 2, \ldots, n$ has n_i elements
  - The cross product (Cartesian product, set direct product, product set) is required. i.e.

$$A_1 \times A_2 \times \ldots \times A_n = \prod_{i=1}^{n} A_i$$

  - having $\prod_{i=1}^{n} n_i$ elements which will

    be generated in a vector, $p=[\, p_1\, p_2 \ldots\, p_n]$

Cross product algorithm

- Set every element of vector p to 1.
  - This is the first element of the cross product
- Find next element as follows:
  - Find the highest index i for which $p_i < n_i$.

    If such an index cannot be found then all elements have been generated. Stop
  - Find next element of the cross product as

    $\{p_1, p_2, p_{i-1}, p_{i+1}, 1, 1, \ldots, 1\}$

Cross product implementation. Non recursive

```
#include <stdio.h>
#define MAXN 10
void listProduct(int n, int
   prodNb, int p[])
{
   int i;
   printf("\n%3d ", prodNb);
   for (i = 1; i <=n; i++)
   printf(" %2d", p[i]);
   if ( prodNb % 20 == 0 )
   getch();
}
void crossProdNonRec(int n,
   int nElem[])
/*    n = number of sets;
   nElem = vector with number
   of elements per set */
{
   int i, prodNb, p[MAXN];
   prodNb = 1;
   for (i = 1; i <= n; i++) p[i] = 1;
   listProduct(n, prodNb, p);
   i = n;
   while ( i > 0 )
   {
      p[i]++; // find highest such as p[i] > nElem[i]
      if (p[i] > nElem[i])
      {
         p[i] = 1;
         i--;
      }
      else
      {
         prodNb++;
         listProduct(n, prodNb, p);
         i = n;
      }
   }
}
```

Cross product implementation. Non recursive

```
int main(int argc, char *argv[])
{
  int i, n, nElem[MAXN];
   printf("\nNumber of sets [<%d]=", MAXN); scanf("%d", &n);
   for (i = 1; i <= n; i++)
   {
       printf("Number of elements in set %d=", i);
       scanf("%d", &nElem[i]);
   }
   printf("\nThe members of the cross product");
   printf("\nNo.   Elements");
   crossProdNonRec(n, nElem);
  getchar();
  return 0;
}
```

Cross product implementation. Recursive

```
#include <stdio.h>
#include <conio.h>
#define MAXN 10
int prodNb, p[MAXN],
   nElem[MAXN];
void listProduct(int n)
{
   int i;

   printf("\n%3d ", prodNb);
   for (i = 1; i <=n; i++)
   printf(" %2d", p[i]);
   if ( prodNb % 20 == 0 )
   getch();
}
```

```
void crossProdRec(int n, int i)
/* n = number of sets; nElem =
   vector with number of elements
   per set */
{
   int j;

   for (j = 1; j <=nElem[i]; j++)
   {
     p[i] = j;
     if (i< n) crossProdRec(n, i+1);
     else
     {
       prodNb++;
        listProduct(n);
     }
   }
}
```

Cross product implementation. Recursive

```
int main(int argc, char *argv[])
{
  int i, n;
   printf("\nNumber of sets [<%d]=", MAXN); scanf("%d", &n);
   for (i = 1; i <= n; i++)
   {
       printf("Number of elements in set %d=", i);
       scanf("%d", &nElem[i]);
   }
   printf("\nThe members of the cross product");
   printf("\nNo.   Elements");
   crossProdRec(n, 1);
  getch();
  return 0;
}
```

Combinations

- Let P be a set of n elements
- All ways of picking k unordered elements of the n elements = generating all subsets with $k \leq n$ elements of P such as any two subsets are distinct
  - The number of subsets is the *binomial coefficient* or *choice number* and read "*n* choose *k*"

Combinations algorithm

- First subset is $p=\{1, 2, ..., k\}$
- Given a subset, its successor is found as follows:
  - Going from k down to 1 find index i which satisfies the relationships

$$
\begin{aligned}
p_i &< n-k+i \\
p_{i+1} &= n-k+i+1 \\
&\dots \\
p_{k-1} &= n-1 \\
p_k &= n
\end{aligned}
$$

  - Successor set is:

$$\{p_1, p_2, ..., p_i+1, p_i+2, ..., p_i+n-k+1\}$$

  - The last subset is:

$$\{n-k+1, n-k+2, ..., \ n-1, n\}$$

Combinations algorithm implementation. Non recursive

```
void combinNonRec(int n, int k)
{
    int p[MAXN];
    int i, j, combinNb;
    for (i=1; i <=k; i++) p[i]=i; /* first combination */
    listCombin(k, combinNb, p);
    i = k;
    while (i > 0) /* generate the next combinations */
    {
      p[i]++; // find index satisfying relation set
      if (p[i] > n - k + i) i--;
      else
      {
        for (j = i + 1; ; j <= k; j++) p[j]=p[j-1] + 1;
        combinNb++;
        listCombin(k, combinNb, p);
        i = k;
      }
    }
}
```

Combinations algorithm implementation. Recursive

```
void combinRec(int n, int k, int i)
{
    int j;
    for (j = p[i-1]+1; j <= n-k+i; j++)
    {
      p[i] = j;
      if (i < k) combinRec(n, k, i+1);
      else
      {
       combinNb++;
       listCombin(k, combinNb, p);
      }
    }
}
```

- Notes
  - Array `p`, and `combinNb` must be global
  - Invocation is: `combinRec(n, k, 1)`

Generating Permutations

- For instance 35241 is the permutation that maps 1 to 3, 2 to 5, 3 to 2, 4 to 4, and 5 to 1.
- We know that there are 7! permutations on {1,2,3,4,5,6,7}.
  - Suppose we want to list them all. Is there an efficient way to do so? It turns out to be fairly simple to list them lexicographically.
  - The only hard question is, given one permutation, how do we find the next one?
- The lexicographically first permutation is

$$1\ 2\ \ldots\ n$$

- and the last is

$$n\ n\text{-}1\ \ldots\ 1$$

Generating Permutations

- It is intuitively reasonable that if the final digits of a permutation are in descending order, then no rearrangement will make them larger.
  - For instance in 125*7643* we cannot produce a larger number by rearranging the 7643.
  - Instead we must increase the next most significant digit (the 5) by the next larger digit in 7643 (the 6).
  - Then the remaining digits (the 5 and the 743) must be arranged to form the smallest number possible.
  - Thus the next permutation in lexicographic order is 1263457.

Generating permutations in lexicographical order

a. First permutation is $p = \{1, 2, \ldots n\}$
b. Given vector $p=[p_1\ p_2\ \ldots\ p_n]$ the next permutation is found as follows:
    1. Look from n down to 1 for the highest valued index which satisfies the relationships:

$$p_i < p_{i+1}$$
$$p_{i+1} > p_{i+2} > \ldots > p_n$$

    2. Find the maximum element, $p_k > p_i$ of $p_{i+1}, p_{i+2}, \ldots, p_n$
    3. Swap p_k with p_i
    4. Revert $p_{i+1}, p_{i+2}, \ldots, p_n$ by swapping p_{i+1} and p_n, p_{i+2} and p_{n-1}, a.s.o.

Permutations implementation. Non recursive

```
void permNonRec(int n) {
    int p[MAXN];
    int i, k, permNb = 0;

    /* first permutation, step a */
    for (i = 1; i <= n; i++) p[i] = i;
    listPerm(n, ++permNb, p);
    do /* generate the next permutations */
    {
        i = n - 1;
        while (p[i] > p[i+1] && i > 0) i--; /*
  step b1 */
        if (i > 0) {
            for (k = n; p[i] > p[k]; k--); /*
  step b2 */
            swap( &p[i], &p[k] );  /* step b3 */
            revert(p,  i, n, (n - i ) / 2);
            listPerm(n, ++permNb, p);
        }
    } while (i > 0);
}
```

```
void swap(int *i, int *j)
{
  int temp;
  temp = *i;
  *i = *j;
  *j = temp;
}

void revert(int p[], int i, int n,
  int k)
{
  int j;
  for (j = 1; j <= k; j++)
    swap(p[i+j], p[n+1-j]);
}
```

A note on swapping

- Swapping integers in place

```
void swap(int *i, int *j)
{
   *i += *j; // i == i + j
   *j = *i - *j;// j == i + j - j == i
   *i -= *j; // i == i + j - i == j
}
void swap(int *i, int *j)
{
   *i ^= j; // a == a^b;
   *j ^= *i;// b == b^(a^b)
   *i ^= *j;// a == (a^b)^(b^(a^b))
}
```

Second version based on proof on the nearby table, where a and b are bit positions

			final b	final a
a	*b*	*a^b*	*b^(a^b)*	*(a^b)^(b^(a^b))*
0	0	0	0	0
0	1	1	0	1
1	0	1	1	0
1	1	0	1	1

Permutations implementation. Recursive

```
void permRec(int nb)
{
    int i, j;

    if ( nb == 1 )
    {
      permNb++;
      listperm();
    }
    else
    {
      permRec(nb - 1);
      for (i = 1; i <= nb - 1; i++)
      {
        swap( p[i], p[nb] );
        permRec(nb - 1);
        swap( p[i], p[nb] );
      }
    }
}
```

- Notes
  - Generates recursively permutations of elements p_1 p_2 ... p_{n-1} with p_n in position n
  - Then swaps p_i with p_n for i =1..n-1, and generates all permutations
  - Array `p`, `n`, and `permNb` must be globals
  - First permutation must be initialized separately
  - Invocation: `permRec(n)`
  - Order is not loxicographic

Generating k permutations of n

- For set $p=\{1, 2, ..., n\}$ and $k \le n$, positive
  - generate all k-subsets such any two subsets must differ either in the composing elements or in their order
- Algorithm idea:
  - generate all combinations of n elements taken k, and, for each combination
    - generate the $k!$ permutations

Generating *k* permutations of *n* implementation

```
void arrange(int n, int m, int i) {
    int j, k, r;
    for (j = p[i-1] + 1; j <= n - m + i; j++) // recursively generate combinations
    {
        p[i] = j;
        if (i < m) arrange(n, m, i + 1);
        else
        {
            arrNb++;
            listArrang(m, p);

            for (k = 1; k <= m; k++) v[k] = p[k]; // save combination
            do    // nonrecursively permute combination
            {
                k = m - 1;
                while (v[k] > v[k + 1] && k > 0) k--;
                if (k > 0) {
                    for (r = m; v[k] > v[r]; r--);
                    swap(&v[k], &v[r]);
                    revert(k, m, (m - k) / 2);
                    arrNb++;
                    listArrang(m, v);
                }
            }
            while (k > 0);
        }
    }
}
```

Generating a power set

- We wish to generate all 2^n subsets of set $A=\{a_1,\ldots,a_n\}$ (power set)
  - All subsets of $A=\{a_1,\ldots,a_\mathrm{n}\}$ can be divided to two groups
    - Ones that contain a_n
    - Ones that does not contain a_n
  - Ones that does not contain a_n are all subsets of $\{a_1,\ldots,a_{n\text{-}1}\}$
    - When we have all subsets of $\{a_1,\ldots,a_{n\text{-}1}\}$ we can create all subsets of $\{a_1,\ldots,a_n\}$ by adding all elements with a_n inserted

Generating a power set

- Again, we try to generate all subsets without generating power sets of smaller sets
- We can associate 2^n subsets of n elements set $A=\{a_1,\ldots,a_n\}$ with 2^n bit strings $b_1\ldots b_n$
  - $b_i = 1$ if a_i is element of set
  - $b_i = 0$ if a_i is not element of set
- For 3 elements set $\{a_1,\ a_2,\ a_3\}$
  - 000 – the empty set
  - 111 – the set itself
  - 110 – subset $\{a_1,\ a_2\}$
- We can create bit strings by generating binary numbers from 0 to 2^n-1
- Example:

Bit strings	000	001	010	011	100	101	110	111
Subsets	$\varnothing$	a_3	a_2	a_2, a_3	a_1	a_1, a_3	a_1, a_2	a_1, a_2, a_3

Generating a power set. Non recursive

```
void allSubsetsNR(int n)
{
   int i, setNb, p[MAXN]; // p[i]=1 if element i is a member,
                            // i.e p is a characteristic vector
   setNb=1;
   for (i=1; i<=n; i++) p[i]=0; /*empty set */
   listSet(n, setNb, p);
   for (i=n; i>0; ) /* generate next subsets */
   {
      if (p[i] == 0)
      {
         p[i] = 1;
         setNb++;
         listSet(n, setNb, p);
         i = n;
      }
      else
      {
         p[i] = 0;
         i--;
      }
   }
}
```

Generating a power set. Recursive

```
void allSubsetsRec(int n, int i)
{
   int j;
   for (j=0; j <= 1; j++)
   {
      p[i] = j;
      if (i < n)
         allSubsetsRec(n, i+1);
      else
      {
         setNb++;
         listSet(n, setNb);
      }
   }
}
```

```
void listSet(int n, int
   setNb)
{
   int i;

   printf("\n%3d { ", setNb);
   for (i = 1; i <=n; i++)
      if (p[i] == 1 )
         printf(" %2d,", i);
   printf("\b  }");
   if ( setNb % 20 == 0 )
   getch();
}
```

- Note that array `p` and variable `setNb` must be global

Reading

- Deitel: chapter 11
- Prata: chapter 13
- King: chapter 22
- Supplemental:
  - R. Sedgewick: http://www.cs.princeton.edu/~rs/talks/perms.pdf

Summary

- File handling
  - High level I/O
    - fopen
    - fclose
    - fread
    - fwrite
    - fsetpos, fgetpos, ftell, fseek
- Applications
  - Combinatorial generation: generating subsets
    - Cross product (Cartesian product)
    - Combinations
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    - Arrangements
    - Power set