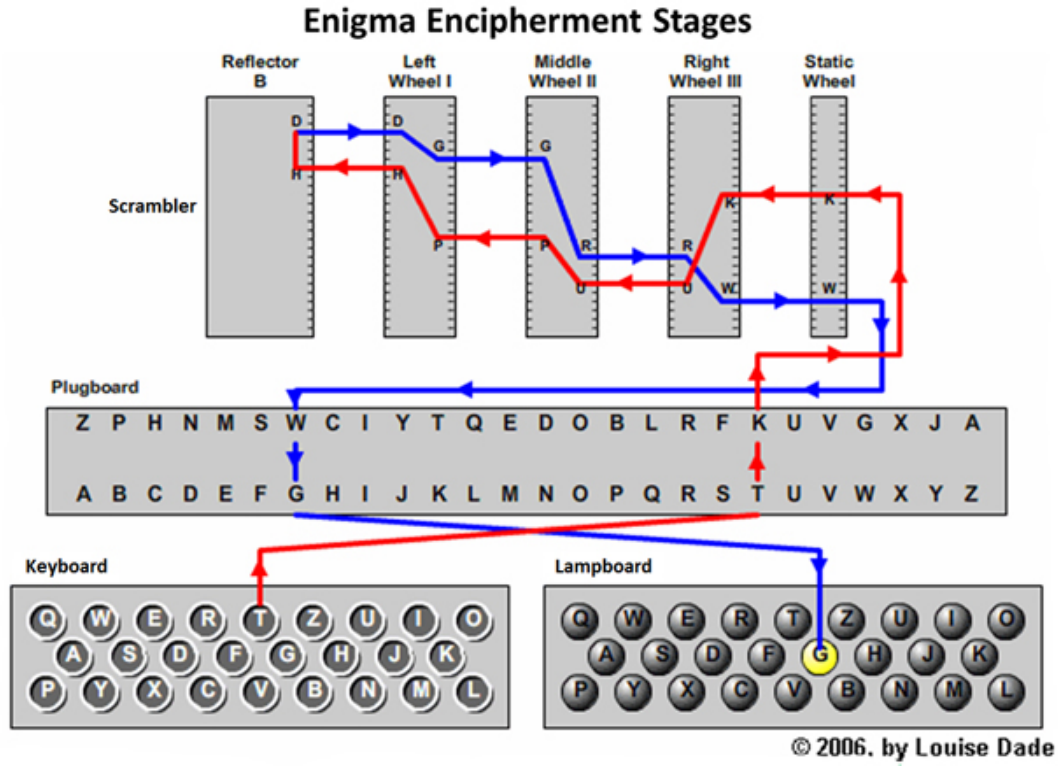
Bombenigma: a simulation of WW2 cryptography

Hystorical recreation and HPC "bruteforce" solution

September 8, 2023 - Livia Giacomin 10709077

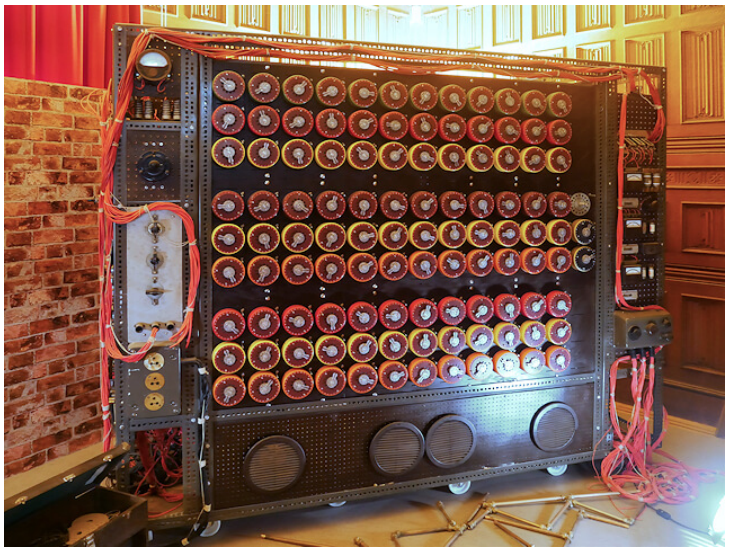
The problem: Enigma machines

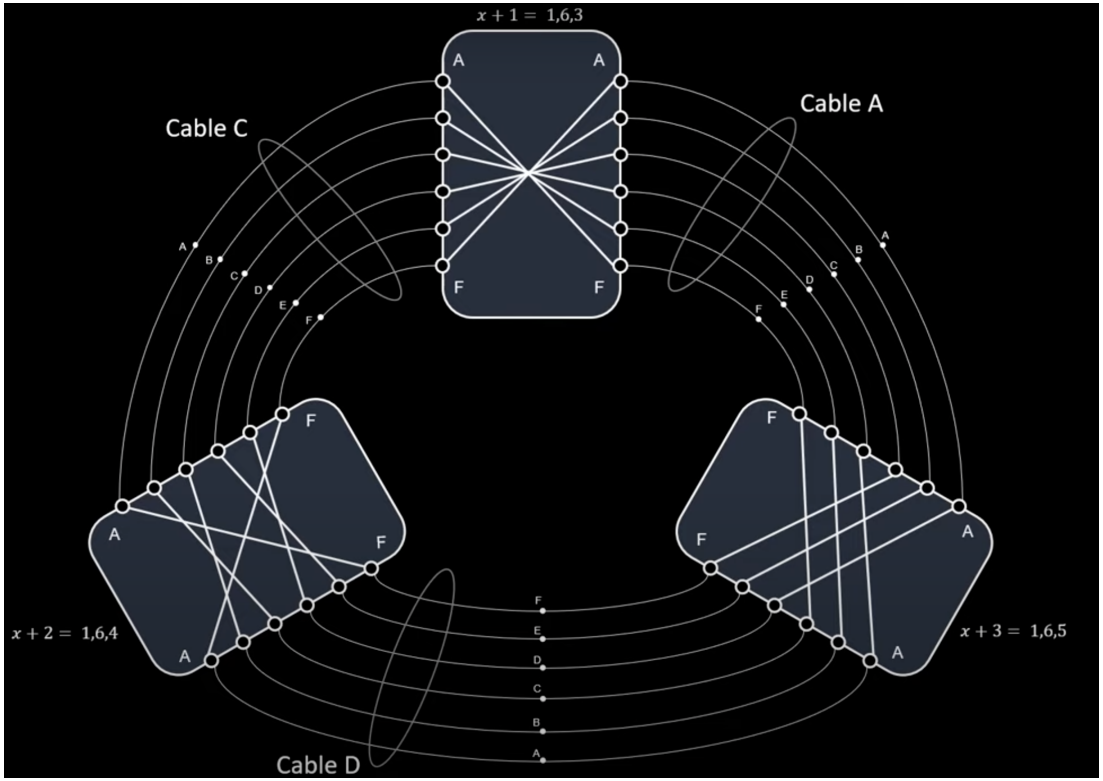


Solving the problem

What were the Enigma's weaknesses? What were cribs?

The original solution: the Bombe





Simulating Enigma: the plugboard/reflector class


```
class Plug_reflect{

private:
    std::vector<int> input_pair1;
    std::vector<int> input_pair2;

public:
    Plug_reflect(const char* path);
    Plug_reflect(std::vector<int>);
    std::vector<int> getpair1();
    std::vector<int> getpair2();
    int map(int input);
  };
```

Simulating Enigma: the rotor class


```
class Rotor{
private:
  int curr_pos;
  int prev_pos;
  int contacts[ALPH_LEN];
  int notch;

public:
  Rotor(const char* path, int start_position);
  int getCurrentPosition();
  int getPreviousPosition();
  void rotate();
  void changePos(int pos);
  int shiftUp(int input_index);
  int shiftDown(int input_index);
  int mapForward(int input_index);
  int mapBackward(int contact);
  bool isItNotch();
  vector<int> getNotchAndPos();
  vector<int> getContacts();
};
```

Simulating Enigma: the enigma class


```
class Enigma{
private:
vector<Rotor> rotors;
vector<int> rotor_positions;
int num_of_rotors;
Plug_reflect *plugboard{nullptr};
Plug_reflect *reflector{nullptr};

public:
  Enigma(int argc, char** argv);
  Enigma(vector<int> rotor_indexes, vector<int> rotor_pos, vector<int> plugboard, int reflector_index);
  void PlugboardConfig(const char* path, vector<int>& contacts);
  void PlugboardConfig2(const char* path, vector<int>& contacts);
  void ReflectorConfig(const char* path, vector<int>& contacts);
  void RotorConfig(const char* path, vector<int>& contacts);
  void RotorPositionConfig(const char* path);
  bool PlugboardCheck(const char* path, fstream& in_stream, int& index_num);
  bool RangeCheck(int num);
  int AppearedBefore(vector<int> contacts, int num, int position);
  void timetravel(int time);
  void set_pos(vector<int> pos);
  void encryptMessage(char& letter);
  void printEnigma();
};
```

Useful functions: getcribs


```
vector<string> getCribs(string output, string key){
   int len = key.size();
   int len2 = output.size();
   int check=0;
   string crib="";
   vector<string> cribs;
   for (int i=0; i<len2-len+1; i++){
    for (int j=0;j<len; j++){
      if (output[i+j]==key[j]) check = 1;
      crib += output[i+j];
    }
    if (check == 0) cribs.push_back(crib);
    crib = "";
    check = 0;
   }
   return cribs;
}
```

Useful structures: codePairs


```
struct codePair{
    char letter1;
    char letter2;
    int pos;
 const {
        if (letter1 != other.letter1) {
            return letter1 < other.letter1;
        } else if (letter2 != other.letter2) {
            return letter2 < other.letter2;
        } else {
            return pos < other.pos;
        }
    }
    bool operator==(const codePair& other) const {
    return letter1 == other.letter1 && letter2 == other.letter2 && pos == other.pos;
}
};

set<codePair>  readMatches(string key, string crib, int cribPos){
  set<codePair> codePairs;
  int len = key.size();
  for (int i=0; i<len;i++){
    if (key[i]<=crib[i]) codePairs.insert({key[i], crib[i],i+cribPos});
    else codePairs.insert({crib[i], key [i],i+cribPos});
  }
  return codePairs;
}
```

Useful functions: findLoop


```
vector<codePair> findLoop(set<codePair> pairs){
  vector<codePair> loop;
  char temp;
  for (codePair pair1 : pairs){
    if (!loop.empty()) break;
    for (codePair pair2 : pairs){
      temp=pair1.letter2;
      if (!(pair1==pair2)){
        if (pair2.letter1==temp) temp=pair2.letter2;
        else if (pair2.letter2==temp) temp=pair2.letter1;
        else continue;
      for (codePair pair3 : pairs){
        if (!(pair3==pair2)&&!(pair3==pair1)){
          if (pair3.letter1==temp) {
            if (pair1.letter1==pair3.letter2){
              loop.push_back(pair1);
              loop.push_back(pair2);
              loop.push_back(pair3);
              return loop;}}
          else if (pair3.letter2==temp) {
            if (pair1.letter1==pair3.letter1){
              loop.push_back(pair1);
              loop.push_back(pair2);
              loop.push_back(pair3);
              return loop;
        }}}}}}
return loop;}
```

Bombe code: finding the crib and loop


```
int main(int argc, char** argv){
    vector<string> outputs = encodeFullMessages(argc, argv);
    for (string output : outputs){
    string key= getKeyFromFile();
    vector<string>  cribList = getCribs(output, key);
    int n_cribs=cribList.size();
    cout << "number of cribs found: " <<n_cribs<<endl;
    if (n_cribs==0) {
    cout << "There are no cribs, so our Bombe cannot decode this message."; return 0; }
    vector<codePair> loop;
    int cribPos;
    for (string crib : cribList){//we try for all cribs
      cribPos=output.find(crib);
      set<codePair> codePairs = readMatches(key,crib,cribPos);
      loop = findLoop(codePairs);
      if (!loop.empty()) {
        cout << "Loop of three pairs of letters found in the crib " << crib <<": " ;
        cout << "(crib position "<<cribPos<< ") ";
          for (const codePair& pair : loop) {
            cout << "(" << pair.letter1 << ", " << pair.letter2 << ", "<< pair.pos <<") ";
          }
          cout << endl;
          }
    if (loop.empty()){
      cout << "No loops found in the crib "<<crib<<endl;
      continue;
      }
```

Bombe code: executing the machine


```
vector<int> rotor_indexes = {1, 2, 3};
   int reflector_index = 1;
   Enigma *enigma = startEnigma(rotor_indexes,{},reflector_index);
   string trial;
   int check=0;
    for (int i=0;i<ALPH_LEN;i++){
    for (int j=0;j<ALPH_LEN;j++){
       for (int k=0;k<ALPH_LEN;k++){
         trial={};
         trial+='A';
         enigma->set_pos({i,j,k});
         enigma->timetravel(loop[0].pos+cribPos);
         trial+=encode(enigma,trial).back();
         enigma->set_pos({i,j,k});
         enigma->timetravel(loop[1].pos+cribPos);
         trial+=encode(enigma,trial).back();
         enigma->set_pos({i,j,k});
         enigma->timetravel(loop[2].pos+cribPos);
         trial+=encode(enigma,trial).back();
```

Bombe code: executing the machine


```
if (trial.back()=='A') {
            check=1;
            cout << "potential settings found with rotor positions "<<i<<" "<<j<<" "<<k<<"."<<endl<<
            "The plugboard settings would be: "<< endl;
            vector<char> loop_plugs={};
            loop_plugs.push_back(loop[0].letter2);
            if (loop[0].letter2!=loop[1].letter1) loop_plugs.push_back(loop[1].letter1);
            else loop_plugs.push_back(loop[1].letter2);
            loop_plugs.push_back(loop[0].letter1);
            for (int m=0; m<loop_plugs.size();m++){
              cout << loop_plugs[m]<<" "<<trial[m]<< " // ";
            }
            cout<<endl;
            break;
          }
        }
      }
   } if (check==0) cout << "No potential settings found with this crib."<<endl;
   delete enigma;
    }
```

Bombe code: output snippet


```
The message we try to decode is GVNJQZCZMXQJFSSTBLQRKRVXWMANBXZRXAB
number of cribs found: 11
No loops found in the crib VNJQZCZMXQJFSSTBLQR
No loops found in the crib JQZCZMXQJFSSTBLQRKR
No loops found in the crib QZCZMXQJFSSTBLQRKRV
Loop of three pairs of letters found in the crib ZCZMXQJFSSTBLQRKRVX: (crib position 5)
(O, T, 15) (T, X, 9) (O, X, 23)
potential settings found with rotor positions 0 0 22.
The plugboard settings would be:
T A // X I // O E //
potential settings found with rotor positions 0 1 8.
The plugboard settings would be:
T A // X Z // O P //
potential settings found with rotor positions 0 2 12.
The plugboard settings would be:
T A // X E // O H //
potential settings found with rotor positions 0 4 4.
The plugboard settings would be:
T A // X R // O G //
potential settings found with rotor positions 0 5 9.
The plugboard settings would be:
T A // X B // O G //
```

Bombe code: useful?

Did the Bombe always work?
Does this code guarantee a solution?

The power of bruteforce

Modern problems require modern solutions: considering all plugboard cases

```
ofstream outFile("pluglist.txt");
for (int i=0;i<ALPH_LEN;i++){
   for (int j=0;j<i;j++){
    temp.first=i;
    temp.second=j;
    plugs.push_back(temp); }}
vector<vector<plug>> plugboards;
vector<plug> plugboard;
int len=plugs.size();
for (int i=0;i<len;i++){
   for (int j=0;j<i;j++){
    if (!shareletter(plugs[i],plugs[j])){
        for (int k=0;k<j;k++){
            if (!shareletter(plugs[k],plugs[j])&&!shareletter(plugs[k],plugs[i])){
                plugboard={};
                plugboard.push_back(plugs[k]);
                plugboard.push_back(plugs[j]);
                plugboard.push_back(plugs[i]);
                plugboards.push_back(plugboard);
                outFile << plugboard[0].first<<" "<<plugboard[0].second<<
                " "<<plugboard[1].first<<" "<<plugboard[1].second<<" "<<plugboard[2].first
                <<" "<<plugboard[2].second<<endl;
            }}}}}
```

Bruteforce solution: setup


```
int main(int argc, char** argv){
   auto start_time = chrono::high_resolution_clock::now();
    vector<string> outputs = encodeFullMessages(argc, argv);
    string output=outputs.front();
    vector<vector<int>> plugboards={};
    vector<int> plugboard;
    string line;
    ifstream pluglist("pluglist.txt");
    while (getline(pluglist, line)) {
        plugboard=readplug(line);
        plugboards.push_back(plugboard);}
    string key= getKeyFromFile();
    vector<string>  cribList = getCribs(output, key);
    reverse(cribList.begin(), cribList.end());
    int n_cribs=cribList.size();
    int cribPos;
```

Bruteforce: HPC iterations


```
int threads=min(n_cribs,8);
 #pragma omp parallel for num_threads(threads) shared(cribList) private(cribPos)
    for (string crib : cribList){//we try for all cribs
      cribPos=output.find(crib);
    vector<int> rotor_indexes = {1, 2, 3};
    int reflector_index = 1;

     #pragma omp parallel for num_threads(threads) private(plugboard)
     for (vector<int> plugboard:plugboards) {
        Enigma *enigma = startEnigma(rotor_indexes,plugboard,reflector_index);
        string decoded;
        for (int i=0;i<ALPH_LEN;i++){
          for (int j=0;j<ALPH_LEN;j++){
            for (int k=0;k<ALPH_LEN;k++){
              enigma->set_pos({i,j,k});
              enigma->timetravel(cribPos);
              decoded=encode(enigma,crib);
              if (decoded==key){
                 ...
```

Bruteforce: HPC iterations


```
if (decoded==key){
                 auto end_time = chrono::high_resolution_clock::now();
                cout<<"Found solution at rotor positions "<<i<<" "<<j<<" "<<k<<"."
                <<endl<<"with plugboard settings ";
                for (int a : plugboard){
                  char letter = 'A' + a;
                  cout << letter << " ";}
                cout<< endl;
                enigma->set_pos({i,j,k});
                cout<<"Decoded messages: "<<endl;
                for (string code :outputs){
                  cout<<encode(enigma,code)<<endl;
                }
                delete enigma;

                auto elapsed_time = chrono::duration_cast<chrono::seconds>(end_time - start_time);
                cout << "Time taken: " << elapsed_time.count() << " seconds" << endl;
                exit(0);
```

Bruteforce:results


```
Found solution at rotor positions 25 1 8.
with plugboard settings D A F C G B
Decoded messages:
LEZIONISOSPESEALPOLITECNICODIMILANO
CLIMATIZZATORIACCESIALPOLITECNICODIMILANO
STUDENTIFUORISEDEAFFOLLANOILPOLITECNICODIMILANO
ATTACCOPROGRAMMATOINPIAZZALEODAVANTIALPOLITECNICODIMILANO
Time taken: 32 seconds
```

Takeaway and historical relevance

Why was the Bombe relevant? What has it changed in the history of computing?
Thanks for your attention!