Licenciatura em Engenharia Informática

Algoritmos e Estruturas de Dados

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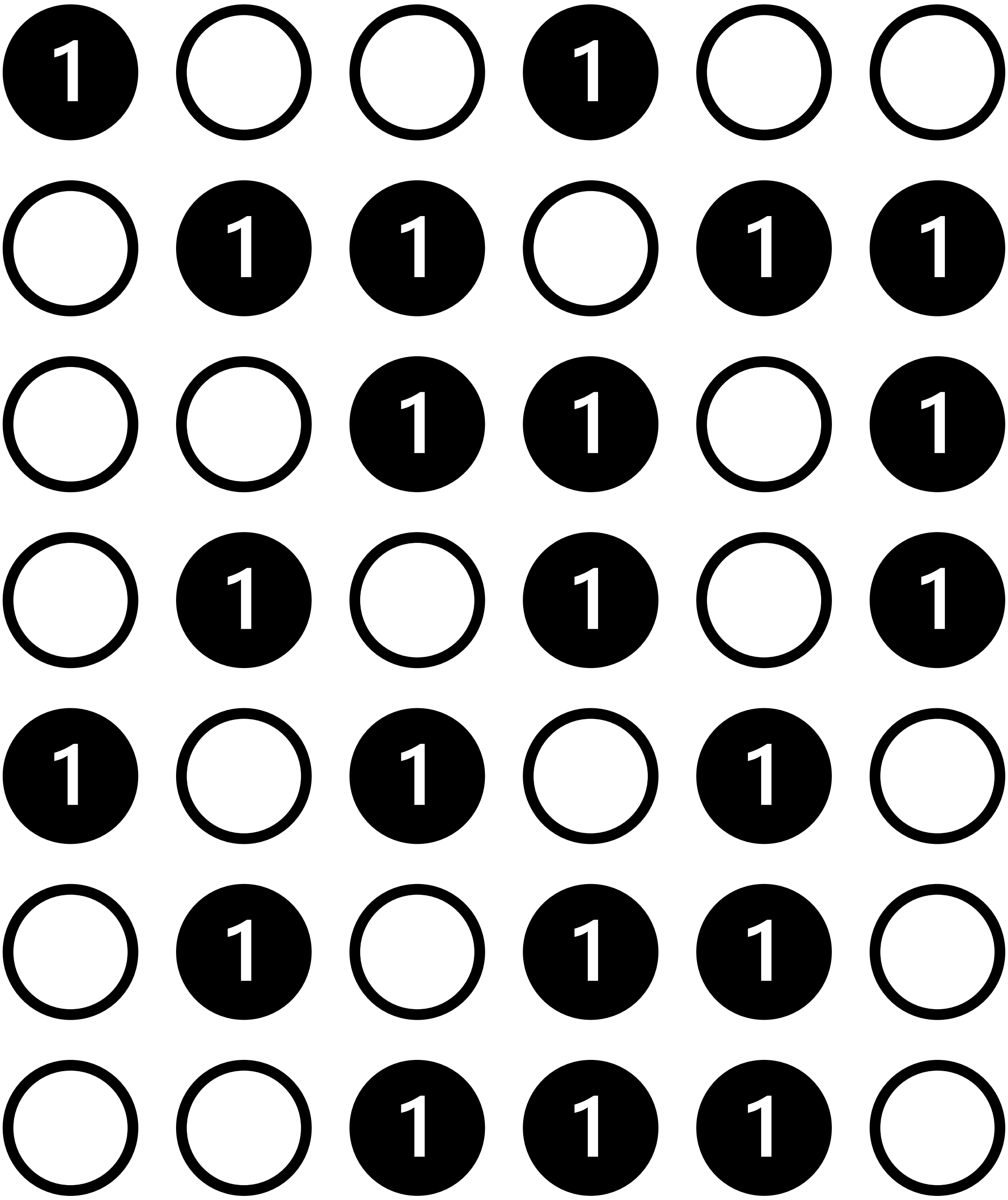

The Merkle-Hellman Cryptosystem

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Introdução

A criptografia é usada na comunicação de dados para proteger mensagens que circulam em canais de comunicação pouco seguros. Só na década de 70, com o aparecimento dos sistemas criptográficos de chave pública ou assimétrica, veio-se resolver o problema do transporte seguro de chaves.

O objetivo deste trabalho é a implementação e estudo de diversos algoritmos de decifragem do sistema criptográfico de Merkle-Hellman.

O problema proposto consiste na identificação de um subconjunto de um dado conjunto de números fornecido a priori, onde a soma dos elementos desse subconjunto corresponde à solução pretendida. O resultado final é apresentado na forma de uma *mask* onde o índice dos bits a 1 indica a posição no conjunto fornecido dos valores pertencentes ao subconjunto.

Para a resolução do problema foram implementados vários algoritmos de modo a mostrar as vantagens e desvantagens de cada um, onde os resultados obtidos vão ser descritos neste relatório.

Contextualização do Problema

Como referido anteriormente, o problema proposto (***subset sum problem***) consiste num conjunto de $\boldsymbol{n}$ inteiros positivos $\boldsymbol{P} = (p_0, p_1, \ldots, p_{n-1})$ e ainda um inteiro positivo $\boldsymbol{x}$. O objetivo do problema é identificar um subconjunto único $\boldsymbol{S} \subset \boldsymbol{P}$ onde:

$$x = \sum_{i=0}^{n-1} S_i$$

De modo a apresentar o resultado de uma forma clara, este vai ser representado na forma de uma *mask* $\boldsymbol{M} = (m_0, m_1, \ldots, m_{n-1})$ onde $m_i \subset \{0,1\}$ tal que:

$$x = \sum_{i=0}^{n-1} p_i \, m_i$$

O exemplo a seguir demonstra uma solução do problema.

$$\boldsymbol{P} = (234, 429, 769, 835, 858, 874, 998, 1200, 1592, 1655)$$

$$\boldsymbol{x} = 5963$$

$$\boldsymbol{S} = (429, 769, 835, 858, 874, 998, 1200)$$

$$\boldsymbol{M} = (0,1,1,1,1,1,1,1,0,0)$$

Para alcançar as soluções, foram implementados quatro algoritmos: *Bruteforce*, *Clever Bruteforce*, *Horowitz* e Sahni, *Schroeppel* e *Shamir*, que vão ser explicados a seguir.

Brute Force

O método ***Brute Force***, consiste numa implementação recursiva, onde são calculadas todas as combinações possíveis de *masks* até que ***M*** seja encontrado.

Assim, é passado como parâmetros de entrada o vetor ***P*** e o seu tamanho ***n***, o nível de recursividade ***level***, inicialmente a 0, a soma obtida até ao momento ***partial_sum***, a soma pretendida ***desired_sum*** e a *mask* a ser testada ***mask***.

A função começa por avaliar os casos de término, quando ***level*** é maior que ***n***, significa que a solução não foi encontrada e, se ***partial_sum*** é igual ***desired_sum***, o que significa que ***x*** foi encontrado.

O comportamento recursivo da função pode ser representado através de uma árvore onde cada nó representa uma ***partial_sum***. Cada nó pai vai ter dois nós filho, onde $\boldsymbol{M}_{level}$ vai estar a 0 ou a 1 respetivamente, construindo assim todas as ***M*** possíveis. Ao verificar todas as hipóteses possíveis, este método vai ter $\mathcal{O}(2^n)$ de execução para $\boldsymbol{M}_n$.

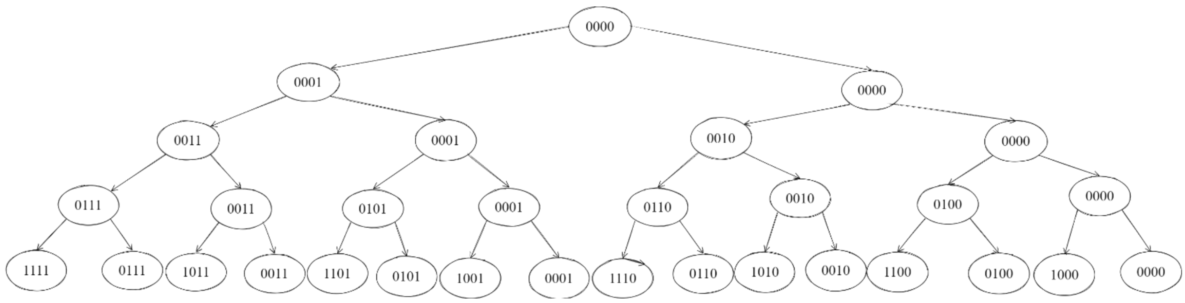

Figura 1- Árvore para n=4

Clever Brute Force

O método ***Clever Brute Force***, tal como o nome indica, é uma versão do algoritmo explicado anteriormente, mas com otimizações que removem logo casos improváveis.

São passados como parâmetros os mesmos do método anterior e um vetor ***sums*** onde

$$\boldsymbol{Sums_1} = \boldsymbol{P}_1 \text{ e } \boldsymbol{Sums}_i = \sum_{j=2}^{n} \boldsymbol{Sums}_{j-1} + \boldsymbol{P}_j$$

Este método é mais eficiente que o anterior porque é efetuado o *pruning* de certos nós da árvore que nunca iriam resultar em $\boldsymbol{S}$. É sabido do problema que $\forall p \in P, p_i < p_{i+1}, i \in N$ então, se $\boldsymbol{partial\_sum} + \boldsymbol{Sums}_{level} < \boldsymbol{x}$ a *mask* que está a ser testada já não candidata a solução. Sendo assim, ao invés de testar de forma crescente as máscaras, começando com $\boldsymbol{P_0}$ começa-se a testar para P_{n-1} e de forma decrescente para eliminar mais rapidamente *masks*.

No entanto, este método apesar de ser mais eficiente, continua a ter de complexidade de execução $\mathcal{O}(2^n)$, visto que para o pior dos casos vai ter de testar todas as combinações possíveis.

Horowitz and Sahni Technique

O método *meet-in-the-middle*, idealizado por *E. Horowitz* e *S. Sahni* e tem como intento subdividir o problema. ***P*** é dividido em dois subconjuntos de tamanhos aproximadamente iguais, ***A*** e ***B*** e são geradas e guardadas em dois vetores todas as somas possíveis de cada subconjunto, ***sumsA*** e ***sumsB*** com tamanho aproximadamente $2^{n/2}$. Os vetores de somas são ordenados com recurso ao algoritmo *quicksort* por ordem crescente.

Sabendo que se $sumsA_i + sumsB_j = x$ então a solução foi encontrada. Para isto acontecer os dois vetores são percorridos por ordem crescente e decrescente, respetivamente e, caso $sumsA_i + sumsB_j < x$, *i* é incrementado e se $sumsA_i + sumsB_j > x$, j é decrementado. Caso $i > n_{sumsA}$ ou $j < 0$, a solução não foi encontrada.

Este método, reduz drasticamente a complexidade comparativamente aos métodos apresentados anteriormente tendo $O(n2^{n/2})$ na execução, permitindo calcular soluções para ***n***'s maiores. Contudo, ao calcular ***sumsA*** e ***sumsB*** há um grande dispêndio de memória.

[1] Ao correr o ficheiro *subset_sum_problem.c* o cálculo de ***sumsA*** e ***sumsB*** são efetuados antes de executar o algoritmo, visto que, para cada conjunto de problemas de tamanho igual, ***P*** é sempre o mesmo.

Schroeppel and Shamir Technique

O método de *Schroeppel* e *Shamir* surge com o objetivo de otimizar o método anterior ao reduzir a necessidade de bastante memória. Para isso ao invés de dividir ***P*** em 2, divide em 4 subconjuntos de tamanhos aproximadamente iguais, são gerados os vetores de somas ***sumsA***, ***sumsB***, ***sumsC*** e ***sumsD*** e estes são ordenados recorrendo outra vez ao algoritmo *quicksort*.

Os vetores ***sumsA*** e ***sumsB*** são usados para popular a *minHeap*, onde a raiz é a menor soma possível e ***sumsC*** e ***sumsD*** são usados para popular a *maxHeap*, onde a raiz é a maior soma possível. As *heaps* são usadas para gerar as somas entre os pares de subconjuntos *on the fly* para evitar o enorme consumo de memória ao calcular a soma quando essa é necessária.

Seguindo o método anterior, verifica se a soma das raízes das heaps é a soma pretendida. Caso a ***partial_sum*** seja maior que ***desired_sum*** a raiz da *maxHeap* é eliminada e substituída pelo próximo elemento e, se ***partial_sum*** seja menor ***desired_sum*** a raíz da *minHeap* é eliminada e substituída pelo próximo elemento.

Este método apresenta complexidade $\mathcal{O}\left(\frac{n}{4}2^{\frac{n}{2}}\right)$, na execução e $\mathcal{O}\left(2^{\frac{n}{4}}\right)$ de memória, conseguindo assim corrigir o problema de memória do algoritmo anterior, conseguindo assim quebrar a barreira dos 64 bits.

Resultados Obtidos

Otimizações

Ao longo do desenvolvimento dos métodos implementados, foram feitas otimizações de código que melhoraram a performance de cada um. É de se destacar a conversão de ciclos em funções recursivas para o cálculo das somas, o uso de apontadores na divisão de ***P*** nos dois últimos métodos para evitar alocação de memória desnecessária e ainda a conversão da maioria das operações para operações *bitwise*.

Gráficos

Em cada um dos gráficos apresentados a seguir vai ser analisada a performance de cada um dos algoritmos consoante o ***N***.

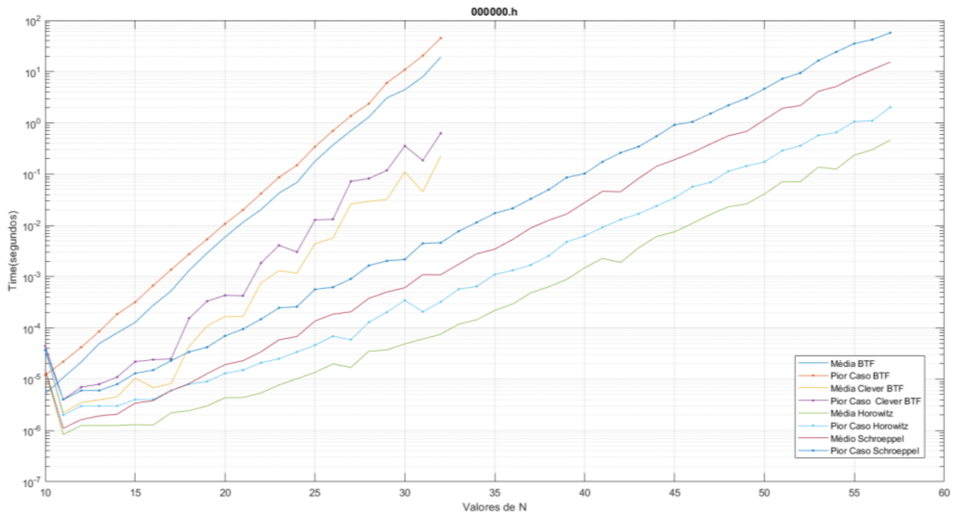

*Figura 2- Gráfico do Tempo em função de **N** de 000000.h*

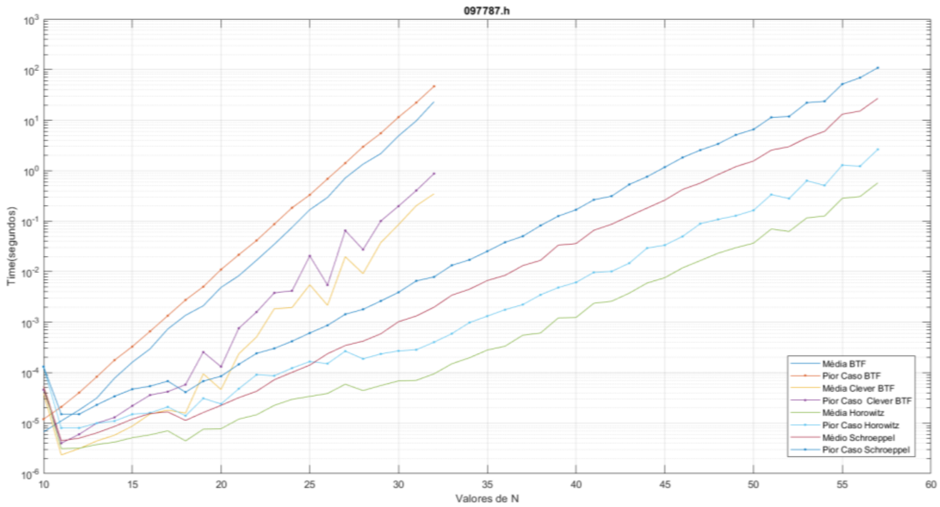

*Figura 3 - Gráfico do Tempo em função de **N** de 097787.h*

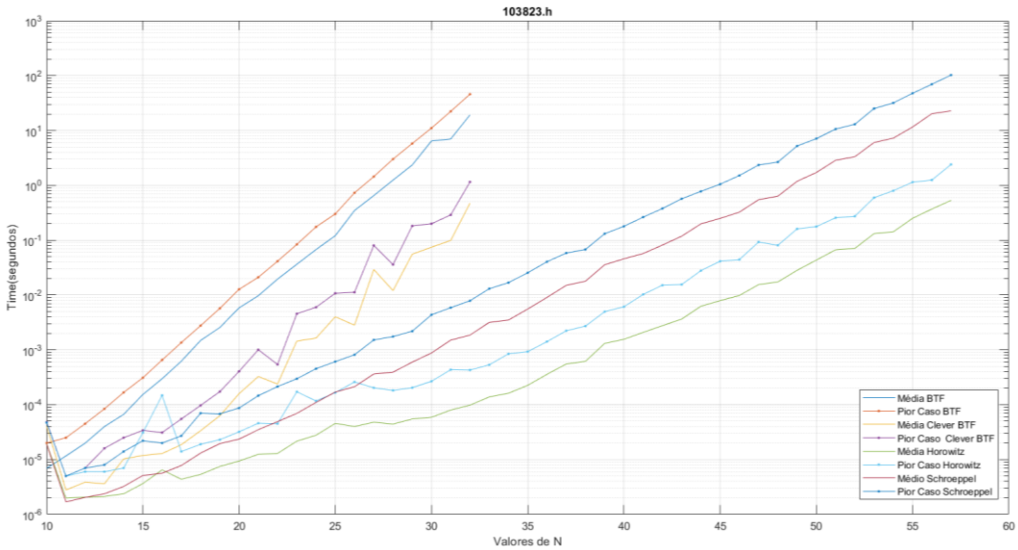

*Figura 4- Gráfico do Tempo em função de **N** de 103823.h*

Pode-se aperceber facilmente que os algoritmos tiveram comportamentos semelhantes em todos os ficheiros fornecidos (000000.h, 097787.h e 103823.h), onde se destaca a fraca performance do *Brute Force* com uma diferença acentuada para *o Clever Brute Force*, este que apesar de apresentar melhorias à sua versão não otimizada, continua a ter um crescimento abrupto.

O método *Horowitz e Sahni* para **n**'s relativamente pequenos tem um comportamento inferior aos *Brute Forces*, mas à medida que **n** vai aumentando, é facilmente percetível que consegue superar os métodos anteriores conseguindo alcançar valores de n muito superiores.

O método *Schroeppel e Shamir*, tem um comportamento semelhante ao *Horowitz e Sahni* para **n**'s pequenos, consegue ter uma eficiência muito maior, devido ao facto de não ter de calcular conjuntos de somas tão grandes, nem de as ter de guardar em memória durante toda a sua execução.

Todos os valores usados neste relatório foram obtidos sempre com a mesma máquina com as seguintes caraterísticas: Intel(R) Core (TM) i7-9750H CPU @ 2.60GHz 2.59 GHz; 16,0 GB RAM; Ubuntu 20.04.3 LTS e todos os valores usados para a construção dos gráficos foi incluído o cálculo das somas.

Conclusão

Com este trabalho, foi possível perceber o quão importante é a procura de várias soluções para o mesmo problema, para perceber as vantagens e desvantagens de cada um deles. Serviu também para aprender mais sobre as técnicas de otimização de código em C e para compreender a necessidade de gestão da memória que o programa precisa para correr.

Referências

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Anexos

Nesta secção está disponibilizado o código C que foi desenvolvido para as várias soluções apresentadas neste relatório e ainda o código Matlab utilizado para processar os resultados obtidos.

Código C

```c
int bruteforce_iterativo(int n, integer_t p[n], integer_t desired_sum, integer_t * b) {
   for (int mask = 0; mask < 1 << n; mask++) {
      integer_t partial_sum = 0;
      for (int bit = 0; bit < n; bit++) {
         if (mask & (1 << bit))
            partial_sum += p[bit];
      }
      if (partial_sum == desired_sum) {
         * b = mask;
         return 1;
      }
   }
   return 0;
}
```

```c
int bruteforce_recursivo(int n, integer_t p[n], int level, integer_t partial_sum, integer_t desired_sum, integer_t
mask, integer_t * b) {
   if (level > n) {
      return 0;
   }
   if (partial_sum == desired_sum) {
      * b = mask;
      return 1;
   }

   if (bruteforce_recursivo(n, p, level + 1, partial_sum + p[level], desired_sum, (mask | (1 << level)), b)) {
      return 1;
   } else {
      return bruteforce_recursivo(n, p, level + 1, partial_sum, desired_sum, mask, b);
   }

}
```

```c
int bruteforce_recursivo_otimizado(int n, integer_t p[n], int level, integer_t partial_sum, integer_t desired_sum, integer_t mask,
integer_t * b, integer_t * sums) {
   if (partial_sum == desired_sum) {
      * b = mask;
      return 1;
   }

   if (level < 0 || partial_sum > desired_sum || partial_sum + sums[level] < desired_sum) {
      return 0;
   }

   if (bruteforce_recursivo_otimizado(n, p, level - 1, partial_sum + p[level], desired_sum, (mask | (1 << (level))), b, sums)) {
      return 1;
   } else {
      return bruteforce_recursivo_otimizado(n, p, level - 1, partial_sum, desired_sum, mask, b, sums);
   }
}
```

```c
typedef struct {
   integer_t mask;
   integer_t sum;
}
mask_data_t;

void swap(mask_data_t * a, mask_data_t * b) {
   mask_data_t t = * a;
   * a = * b;
   * b = t;
}

int partition(mask_data_t arr[], int low, int high) {
   mask_data_t pivot = arr[high]; // pivot
   int i = (low - 1); // Index of smaller element and indicates the right position of pivot found so far

   for (int j = low; j <= high - 1; j++) {
      // If current element is smaller than the pivot
      if (arr[j].sum < pivot.sum) {
         i++; // increment index of smaller element
         swap( & arr[i], & arr[j]);
      }
   }
   swap( & arr[i + 1], & arr[high]);
   return (i + 1);
}

void quicksort(mask_data_t arr[], int low, int high) {
   if (low < high) {
      /* pi is partitioning index, arr[p] is now
      at right place */
      int pi = partition(arr, low, high);
      // Separately sort elements before
      // partition and after partition
      quicksort(arr, low, pi - 1);
      quicksort(arr, pi + 1, high);
   }
}

void sums_generator(int n, integer_t p[n], mask_data_t result[1 << n], int level, integer_t mask, integer_t subSum, int idx) {
   if (level == n) {
      result[idx].sum = subSum;
      result[idx].mask = mask;
      return;
   }
   sums_generator(n, p, result, level + 1, mask | (1 << level), subSum + p[level], 2*idx);
   sums_generator(n, p, result, level + 1, mask, subSum, 2*idx+1);
}


int horowitz_sahni(int n, integer_t p[], integer_t desired_sum, integer_t * b_result, mask_data_t *sumsA, mask_data_t *sumsB,
int nA, int nB) {
   int i = 0, j = (1 << nB) - 1;
   while (i < (1 << nA) && j >= 0) {
      if (sumsA[i].sum + sumsB[j].sum == desired_sum) {
         *b_result = sumsA[i].mask | (sumsB[j].mask << nA);
         return 1;
      } else if (sumsA[i].sum + sumsB[j].sum < desired_sum) {
         i++;
      } else {
         j--;
      }
   }
   return 0;
}


typedef struct {
   integer_t mask;
   integer_t sum;
   int i0;
   int i1;
} heapData_t;

void minheapInsert(heapData_t heap[], heapData_t element, int* heapSize)
{
    int i;
    for (i = *heapSize; i > 0 && heap[(i - 1) / 2].sum > element.sum; i = (i - 1) / 2)
    {
        heap[i] = heap[(i - 1) / 2];
    }
    heap[i] = element;
    (*heapSize)++;
}
```

```c
heapData_t deleteMin(heapData_t heap[], int* heapSize)
{
   int i, son;
   heapData_t element = heap[0];

   (*heapSize)--;
   for (i = 0; i * 2 + 1 <= *heapSize; i = son) {
      son = 2 * i + 1;
      if (son < *heapSize && heap[son].sum > heap[son + 1].sum)
         son++;
      if (heap[son].sum < heap[*heapSize].sum)
         heap[i] = heap[son];
      else
         break;
   }

   heap[i] = heap[*heapSize];
   return element;
}


void maxheapInsert(heapData_t heap[], heapData_t element, int* heapSize)
{
   int i;
   for (i = *heapSize; i > 0 && heap[(i - 1) / 2].sum < element.sum; i = (i - 1) / 2) {
      heap[i] = heap[(i - 1) / 2];
   }
   heap[i] = element;
   (*heapSize)++;
}

heapData_t deletemax(heapData_t heap[], int* heapSize)
{
   int i, son;
   heapData_t element = heap[0];

   (*heapSize)--;
   for (i = 0; i * 2 + 1 <= *heapSize; i = son) {
      son = 2 * i + 1;
      if (son < *heapSize && heap[son].sum < heap[son + 1].sum)
         son++;
      if (heap[son].sum > heap[*heapSize].sum)
         heap[i] = heap[son];
      else
         break;
   }
   heap[i] = heap[*heapSize];
   return element;
}
```

```c
int schroeppel_shamir (int n, integer_t p[], integer_t desired_sum, integer_t * b_result, mask_data_t *sumsA,mask_data_t *sumsB,
mask_data_t *sumsC, mask_data_t *sumsD,int nA, int nB, int nC, int nD) {
   heapData_t minHeap[1 << nB];
   heapData_t maxHeap[1 << nC];
   int nHMin = 0;
   int nHMax = 0;

   for (int i = 0; i < (1 << nB); i++) {
      heapData_t sum = {
         .mask = sumsA[0].mask | (sumsB[i].mask << nA),
         .sum = sumsA[0].sum + sumsB[i].sum,
         .i0 = 0,
         .i1 = i
      };
      minheapInsert(minHeap, sum, &nHMin);
   }

   for (int i = 0; i < (1 << nC); i++) {
      heapData_t sum = {
         .mask = sumsC[i].mask | (sumsD[(1 << nD) - 1].mask << nC),
         .sum = sumsC[i].sum + sumsD[(1 << nD) - 1].sum,
         .i0 = i,
         .i1 = (1 << nD) - 1
      };
      maxheapInsert(maxHeap,sum,&nHMax);
   }

   while (nHMin > 0 && nHMax > 0){
      integer_t partial_sum = maxHeap[0].sum + minHeap[0].sum;
      if (partial_sum ==  desired_sum) {
         *b_result = minHeap[0].mask | (maxHeap[0].mask << (nA+nB));
         return 1;
      } else if (partial_sum > desired_sum){
         heapData_t old_max = deletemax(maxHeap,&nHMax);
         old_max.i1--;

         if (old_max.i1  >= 0) {
            heapData_t new = {
               .mask = sumsC[old_max.i0].mask | (sumsD[old_max.i1].mask << nC),
               .sum = sumsC[old_max.i0].sum + sumsD[old_max.i1].sum,
               .i0 = old_max.i0,
               .i1 = old_max.i1
            };
            maxheapInsert(maxHeap,new,&nHMax);
         }
      } else {
         heapData_t old_min = deleteMin(minHeap, &nHMin);
         old_min.i0++;
         if (old_min.i0 < (1 << nA)) {
            heapData_t new = {
               .mask = sumsA[old_min.i0].mask | (sumsB[old_min.i1].mask << nA),
               .sum = sumsA[old_min.i0].sum + sumsB[old_min.i1].sum,
               .i0 = old_min.i0,
               .i1 = old_min.i1
            };
            minheapInsert(minHeap, new, &nHMin);
         }
      }
   }
   return 0;
}
```

```c
int main(void) {
   fprintf(stderr, "Program configuration:\n");
   fprintf(stderr, "  min_n ....... %d\n", min_n);
   fprintf(stderr, "  max_n ....... %d\n", max_n);
   fprintf(stderr, "  n_sums ...... %d\n", n_sums);
   fprintf(stderr, "  n_problems .. %d\n", n_problems);
   fprintf(stderr, "  integer_t ... %d bits\n", 8 * (int) sizeof(integer_t));
   //
   // for each n
   //
   for (int i = 0; i < n_problems; i++) {
      int n = all_subset_sum_problems[i].n; // the value of n
      if (n > 42)
         continue; // skip large values of n
      integer_t * p = all_subset_sum_problems[i].p; // the weights
      //
      // for each sum
      //
      double start = cpu_time();
      #ifdef BTF_RCR_OTM
         integer_t * sums = (integer_t * ) malloc(n * sizeof(integer_t));

         sums[0] = p[0];
         for(int i=1; i<n; i++) {
            sums[i] = sums[i-1]+p[i];
         }
      #endif

      #ifdef HW_SN
         int nA = n / 2;
         int nB = n - nA;
         integer_t *a,*b;
         a = p;
         b = p + nA;
         mask_data_t * sumsA = malloc((1 << nA) * sizeof(mask_data_t));
         mask_data_t * sumsB = malloc((1 << nB) * sizeof(mask_data_t));

         sums_generator(nA, a, sumsA, 0, 0, 0, 0);
         quicksort(sumsA, 0, (1 << nA) - 1);

         sums_generator(nB, b, sumsB, 0, 0, 0, 0);
         quicksort(sumsB, 0, (1 << nB) - 1);
      #endif



#ifdef MIM

   int nA = n / 4;
   int nB = n/2 - nA;
   int nC = nB;
   int nD = n - nA-nB-nC;

   integer_t * a = p;
   integer_t * b = p+nA;
   integer_t * c = p+nA+nB;
   integer_t * d = p+nA+nB+nC;
   mask_data_t * sumsA = malloc((1 << nA) * sizeof(mask_data_t));
   mask_data_t * sumsB = malloc((1 << nB) * sizeof(mask_data_t));
   mask_data_t * sumsC = malloc((1 << nC) * sizeof(mask_data_t));
   mask_data_t * sumsD = malloc((1 << nD) * sizeof(mask_data_t));

   //Para o Array A
   sums_generator(nA, a, sumsA, 0, 0, 0, 0);
   quicksort(sumsA, 0, (1 << nA) - 1);

   //Para o Array B
   sums_generator(nB, b, sumsB, 0, 0, 0, 0);
   quicksort(sumsB, 0, (1 << nB) - 1);

   //Para o Array C
   sums_generator(nC, c, sumsC, 0, 0, 0, 0);
   quicksort(sumsC, 0, (1 << nC) - 1);
   //Para o Array D
   sums_generator(nD, d, sumsD, 0, 0, 0, 0);
   quicksort(sumsD, 0, (1 << nD) - 1);
#endif
double end = cpu_time();

printf("%lf\n", end - start);
```

```
        for (int j = 0; j < n_sums; j++) {
            integer_t desired_sum = all_subset_sum_problems[i].sums[j]; // the desired sum
            integer_t b = 0; // array to record the solution
            double start = cpu_time();
            #ifdef BTF_ITR
                bruteforce_iterativo(n, p, desired_sum, & b);
            #endif

            #ifdef BTF_RCR_NOTM
                bruteforce_recursivo(n, p, 0, 0, desired_sum, 0, & b);
            #endif

            #ifdef BTF_RCR_OTM
                bruteforce_recursivo_otimizado(n, p, n - 1, 0, desired_sum, 0, &b, sums);
            #endif

            #ifdef HW_SN
                horowitz_sahni(n, p, desired_sum, &b, sumsA,sumsB,nA,nB);
            #endif

            #ifdef MIM
                schroeppel_shamir(n,p,desired_sum, &b,sumsA,sumsB,sumsC,sumsD,nA,nB,nC,nD);
            #endif

            double end = cpu_time();

            for (int i = 0; i < n; i++) {
                printf("%s", b & 1 ? "1" : "0");
                b = b >> 1;
            }
            printf(" %lf\n", end - start);
        }
        #ifdef BTF_RCR_OTM
            free(sums);
        #endif
        #ifdef HW_SN
            free(sumsA);
            free(sumsB);
        #endif
        #ifdef MIM
            free(sumsA);
            free(sumsB);
            free(sumsC);
            free(sumsD);
        #endif
    }
    return 0;
}
```

Código Matlab

```
function Grafico(namefile,x)
%vai buscar o calculo das somas feitas antes do algoritmo
% bruteforce para cada numero mecanografico (1,2,3)
% clever bruteforce para cada numero mecanografico (4,5,6)
% Horowitz para cada numero mecanografico (7,8,9)
% schroppel para cada numero mecanografico (10,11,12)
switch(x)
    case 1
        somas=load("000000\bruteforce_notz_somas_000000.txt");
    case 2
        somas=load("097787\bruteforce_notz_somas_097787.txt");
    case 3
        somas=load("103823\bruteforce_notz_somas_103823.txt");
    case 4
        somas=load("000000\bruteforce_otz_somas_000000.txt");
    case 5
        somas=load("097787\bruteforce_otz_somas_097787.txt");
    case 6
        somas=load("103823\bruteforce_otz_somas_103823.txt");
    case 7
        somas=load("000000\schroeppel_somas_000000.txt");
    case 8
        somas=load("097787\schroeppel_somas_097787.txt");
    case 9
        somas=load("103823\schoroeppel_somas_103823.txt");
    case 10
         somas=load("000000\schroeppel_somas_000000.txt");
    case 11
        somas=load("097787\schroeppel_somas_097787.txt");
    case 12
        somas=load("103823\schoroeppel_somas_103823.txt");
    case 13
        somas=load("097787\schroppel_somas_128_097787.txt");
    end

    T=load(namefile);%Valores do tempo para cada soma
    T= T+somas';
    [n,~]=size(T);
    N=10:9+n;

    ValorMaximoLinha = max(T'); %ValorMaximoLinha = max(data,[],2);
    %ValorMinimoLinha= min(T'); %ValorMaximoLinha = min(data,[],2);
    media = sum(T,2)/length(N); %media = sum(Q2')/length(N)

    %grafico
    semilogy(N,media)
    hold on
    semilogy(N,ValorMaximoLinha,"•-");
    hold on
    %semilogy(N,ValorMinimoLinha,"•-");
    %hold on
end
```

```
clc
clear
close all

%000000
figure(1)
Grafico ("000000\bruteforce_notz_resultados_somas_000000_organizado.txt",1); %bruteforce para 64 bits
Grafico ("000000\bruteforce_otz_resultados_somas_000000_organizado.txt",4); %clever brute force para 64 bits
Grafico ("000000\horowitz_resultados_somas_000000_organizado.txt",7); %horowitz and sahni technique para 64 bits
Grafico ("000000\schroeppel_resultados_somas_000000_organizado.txt",10); %schroeppel and shamir technique para 64 bits

grid on;
title("000000.h")
legend( "Média BTF", "Pior Caso BTF", "Média Clever BTF", "Pior Caso  Clever BTF", "Média Horowitz",
"Pior Caso Horowitz","Médio Schroeppel ", "Pior Caso Schroeppel");
xlabel("Valores de N");
ylabel("Time(segundos)");
hold off;

%097787
figure(2)
Grafico ("097787\bruteforce_notz_resultados_somas_097787_organizado.txt",2); %bruteforce para 64 bits
Grafico ("097787\bruteforce_otz_resultados_somas_097787_organizado.txt",5); %clever brute force para 64 bits
Grafico ("097787\horowitz_resultados_somas_097787_organizado.txt",8); %horowitz and sahni technique para 64 bits
Grafico ("097787\schroeppel_resultados_somas_097787_organizado.txt",11); %schroeppel and shamir technique para 64 bits
% Grafico ("097787\schroeppel_128_resultados_somas_097787_organizado.txt",13); %schroeppel and shamir technique(128)

grid on;
title("097787.h")
legend( "Média BTF", "Pior Caso BTF", "Média Clever BTF", "Pior Caso  Clever BTF", "Média Horowitz",
"Pior Caso Horowitz","Médio Schroeppel ", "Pior Caso Schroeppel ");
xlabel("Valores de N");
ylabel("Time(segundos)");
hold off;

%103823
figure(3)
Grafico ("103823\bruteforce_notz_resultados_somas_103823_organizado.txt",3); %bruteforce para 64 bits
Grafico ("103823\bruteforce_otz_resultados_somas_103823_organizado.txt",6); %clever brute force para 64 bits
Grafico ("103823\horowitz_resultados_somas_103823_organizado.txt",9); %horowitz and sahni technique para 64 bits
Grafico ("103823\schroeppel_resultados_somas_103823_organizado.txt",12); %schroeppel and shamir technique para 64 bits

grid on;
title("103823.h")
legend( "Média BTF", "Pior Caso BTF", "Média Clever BTF", "Pior Caso  Clever BTF", "Média Horowitz",
"Pior Caso Horowitz","Médio Schroeppel ", "Pior Caso Schroeppel ");
xlabel("Valores de N");
ylabel("Time(segundos)");
hold off;
```

Masks

Nesta secção estão dispostas as soluções obtidas para o problema proposto para cada um dos números mecanográficos.

	097787.h	103823.h
10	1100001110 0100010001 1000011000 0001101101 1100001011 1110111100 0000010111 1010111110 0011101010 0111001100 0101001000 1101000001 0111110110 0010001110 1100011101 0000101100 0011011100 0010100001 1111101100 0001111011	0110101111 0101111111 1010101100 0010111111 0001010010 0010100110 0000011010 0001111101 1011010000 0010001010 0101111100 1100000110 1111111010 1111000000 0010001110 0011010111 1011000101 1001101011 1101111000 1110001111
11	00011101110 01101001110 00100101011 10100111011 11000011101 00010101100 01110011110 10001111000 10111010011 11101010000 00100111010 01000000111 11010000001 10010001001 01111000110 01111111111 10001001010 01101110000 10000101011 01001100010	11100100001 01010001000 11101111111 00001110001 10001011001 10010100100 10000111010 10111001100 00110100010 10001000110 10110011011 01001000111 01010111101 10010010110 00101100111 01110111000 01001001010 01100001110 00111011011 11110100110
12	101110010011 000101111100 111100011111 110000100100 001100101100 000100010100 000101101011 011010000000 010001110100 111000110110 111101101101 110101100011 111111011001 110000110010 100011101101 001111000111 001110010101 110101011101 100010111010 010111110111	011001001011 101001100000 000011011011 001100010010 100110111110 111001100100 011111000010 111110010001 000010111000 110000011111 101001111011 001101101010 001011110010 100101000110 101100101110 111101100100 100011101010 110101101110 000011010110 001011111111
13	1101000011100 1100101010111 1111101100111 0000110011011 0011010100010 1011000110001 1001101111011 1111100001010 1001101011111 0001100011101 1010010110100 0001000010110 1000111110110 1100100000111 1110111010000 0000010101111 1001011111111 1110010011010 1111111110111 0111000110100	0111010010110 0110010110011 0111011000000 1001000001011 0101110000001 0000001100100 1000111001010 1011001001101 1000101010001 0010011111010 1011110010000 0101100100110 1111110011010 0101000100111 1010011100011 1101111110100 0111111001010 1000001001000 0011010000110 0001110111110
14	10100111101010 00010001011100 11011011110111 00010100101101 00011011101011 10110101001000 11111110011111 01000010111001 11110100000000 01011111011111	00110110000101 10111010100100 10111011101110 10011010001001 00110010101111 10010110001010 00000011111010 01011100001101 10010111001011 11010001010101

	11101111111011 00111010110110 01001010101110 10110010111111 00010000111110 11011101111101 00001111110010 11111100100000 00100101001101 01001101111010	11110001101100 11001001011000 11011101110001 11111000010011 01001101100110 11000100100111 00100110111001 10001101100000 10100110110111 10011100010001
15	000111101100111 111101100011010 010101001010110 111010110100011 001001001111011 000111110001100 010010011110111 011010111111011 001010001100111 001100111100111 111001101001000 100001010001011 101100011001000 111011001011110 010110000011010 000100011100101 111011100101101 000111100001000 100000011001101 011110100111100	001111101000010 010011110001001 100010010101010 010111010010001 001111000100000 101010111100111 110000011010011 011011111000111 111111100010110 010101000000100 011010011100111 110010110010010 011000000110100 110111001010011 000111000010001 010011001001000 111101100110100 110000010001101 001000011100110 000101001100011
16	0101000110101110 0000100110000101 0100110001111011 0011001001001010 0100001001010110 0100110001100101 1111001001100011 1011110111001101 1111010110110101 0111001111110111 0011101000001011 1100110100010110 1111100101110010 0110010010101111 0110111010100010 1100010101101110 0000011001000110 1011000111011011 0101111011010010 1111010011000010	0110001100111110 1001001010111001 1110101001011001 1111010101001100 1110010010100001 0010000100001001 1100101100001101 0011010100011011 0010001110010100 1001110001010001 1111110111000001 1110001101110000 1010110111111010 0010001100001100 0110000010100101 0000101000001010 0100000110000001 0000100010100000 1000001101110000 0110100111010100
17	00100010100011110 10100100101110110 11101101100011101 11110001111011011 10101001110001001 00010010111001110 11101010001100010 00010100001000100 00010101001001111 01001111000111001 00111100100110000 01001001001111001 00011010001000011 01101001001001101 11110101010100011 01001011000011100 10011111111101111 00000011110101000 00111100100011101 01100000010110111	00000010011001110 00110001101011010 11010010010100010 10011011101010101 10101001000010111 01111111010000111 10100000101000111 00110110100100100 01111000000101110 11101010011000100 00011010110010000 10111101111100000 10011100010000100 10000111001011111 01101011111101110 11101111110011110 01101101111100111 00100111110101011 00010010111010011 01110000111001100
18	000001111110110111 001110001011111011 010001001101011010 001000101100011110 111101110001111000 000000111100101010 100001010101001101 001011001000110011 101011001101101011 100001101010011001 101011110010010010 100100010110001001 000101001111000111 011101010011010111 110011110101101111 011110001111000101 000100001110011010 001010100001101111 111100011110100101 111000011001001000	101110101001011100 010010011110110000 100001000001111010 011101111011111111 100000010000000011 001100000110100010 100110011111110110 001010111111010011 000010010101111111 111100110001101100 000010001011010000 000001111100110001 001101110011001110 000000110010011011 110101101000001010 000101000101111011 100000001010011111 110101001100110010 001101011111010001 010111100110000010
19	1000010010100101001 1111001101101011110 1000110111010000010 1000100011111000000 0110011011001010010 0111001100110110011 1010010111101010000 1010001001101100001 1100010001110010110 1111110101110100101 0011011010000110011 1100111111010101111 0111001000010010010 1001110011011000011	0110100110011101100 1001101001110100101 1001010100011110100 1010100010011001001 0001101010111111000 0101011000000010100 1001011010011010101 1011101000011001000 1011011011010011011 0010100010010011001 1001011100100101110 1101011101001110110 0011111000101001111 1111011000011011011

	0100110001100001101 1001000101111011111 1001100100010010110 1000001111011011111 0001001010011111110 1001110011111100001	1000101011010100000 0011010101100100101 0101100100100100001 0001110110111000111 1010011100101110000 0001001001111011001
20	10110000001110100011 11001111001111100110 10110101000010101011 01100100101000010000 00001101001101111010 00110010111010110111 11101111111010011101 01011111101110110001 11010000010000010011 01111011100010010011 00101011101101100111 00010011011101011101 10101111111011101110 01111110100010110101 10100000111010011000 01111101010001001101 00101000101011010100 01010100101101000000 10100101110111100101 10111101010100100010	00111000100111100011 11111110010001101110 01100000111110001100 10001111010101101101 01011110000111110011 11100000010100011010 00101001101111011101 10000100100111011110 00110000010000000111 00100011011001100110 00011001111110100110 01101001100010000010 01110011110001001111 10011010010111110101 00111100101010111101 00011000101000001000 10001100000101000101 01010010010001010110 00001100001111011110 11111010011111000001
21	101000011101010111111 001001110100111110010 111000111110010010000 101011100001011110011 101000101110111100111 010100100110011110110 101110111111101100000 000010001100001110010 110010001100011010001 010100010000001000101 100101011100110101110 010101000110010111110 110010011001001101001 100111100001001011011 100010110101100110111 101000110110001011000 111100110010000101001 111001000101000001001 110011001001101111100 000001001110001101011	010111110100011001101 111011111111000110011 011000101000001111111 110010110111011010111 011101000111100101111 000111110001110000101 010101111000001110011 111000010010111000001 100010011100010010111 010110100011010111010 000110010101110101011 001000010000101110110 110000001001001110101 010011111101100111100 000110101001111101111 101010010000111010100 100110000100010100110 111111110010000100001 010100101011100001001 111000011111101010010
22	0110110111001110101111 1000011000101100001011 0110100101000001101101 0110011000011001111011 1101011111100101000010 1001011111101101110011 1110110011011010110100 1011010010011101111110 1010011001011111001111 1111100011011110001101 0100010011101101011101 0001010001110000101000 0011110001011010100111 1100010000101001100011 1111101001011101100101 1110001110111101110000 0100010100110110111000 0101010001111101011101 0100001100011111110011 1011101111000111011001	0111011010000111100110 1001011000011111100011 1000000101111010010011 1111110010110010110001 1010001001010001011010 1100101111111110101100 0010010101111111111101 0001111111010111011101 0001000011110011001010 0001101010111011110110 0000111011010010011011 1011111100101101101101 1000000100011001001110 1000100110011001110101 0101111100001100101010 0101100111101000100100 0011100111011110101110 1101111000100001000011 1111110011111101101001 1111001111010110001110
23	11110010111101100000011 11010101011101011100110 10011110000011111111101 01010001010011101011010 00000010011000010111110 01100101111101101011110 01000000101011000000100 10001111011101000101100 11100101001010110101110 00110000001001011001010 10001001111110100010101 01010110010101011000110 11110110100110001010110 11011011101111010100001 00100110110011001101111 01000110010011111100001 11010110111011100100101 11101110100111001101001 11111111100000001100100 00000001011011011100010	01111110100110011110000 10110010110111001010110 01101000001010001000011 11111110000100101000010 10100100010110010110011 00001010100111101111101 00011101010110001010001 11101001100001011011110 01111110010111100011111 11010001110111010010010 00010011100111111010100 10110101110100001101101 10000101111000011100010 10011101011110011010100 00001101111110000110111 10101101010010111111100 01101010000110010011111 10111101000010010001111 10000111101010001101000 10011101000001000100101
24	110010010000011101001111 101100011000100000111110 110111100000010001110110 011010100011100011110000 000010001110111110111010 000110101010111001001000 010011100111101100100101 000101011111100000110111 010110011001011110010100 111111110111011000110010 011110000111011111000100 111001000101101111100110 101100001010000101100101 011010110101111010100100 010000000111001110011101 101011101010100110010011 101001000101110101011000 100010101101110100010001	010111110111100111011101 000010111010110100101000 101111111011101000001100 111010110100001011100100 111111011100001110010001 111001001110010000001011 100000101101100011011101 001100101111111010010001 110011001110111101101001 000111110010001000100110 111011010111100000100110 100101011100011011111110 011100100100001000100001 111000111000100010011001 100000001110111010010101 000100100100001011001000 101000011011111010011000 110001010000110011000101

	000110100001010101110101 111011111101010110011001	010110000011010110011111 100010000010010110011110
25	1000010000101111110111011 0001000111100001101001100 0111100110111100000010001 1001000011101100010010001 0011110001000010000110100 0001100000101110011001110 0010010011100000100001101 1000000011111011111011111 1001001000011011100101010 1110100100010110111100011 1100011000110010000000001 0101000101000110100101101 0110000110011000010110101 1100101101101000011111111 0001011110110011101010101 1101000101000010100011101 1111100111110001110100100 0010010110010101010010010 1011100001010000011000100 0010111110011010111110010	1010011110000110100100011 1001110001110110001000011 1101111101010011000000101 0111101010111111100000110 0010100111011011000111110 0101111100100001110100101 1011000001101110110101010 1000011100011011110100010 1001100011101111000100110 1000111100110011100010010 0100101101011010010111000 1111100000011001011000110 0110010111000011001000110 1111101001010000101110011 1001111101010110011001010 1101111011110101010111110 1011101000110110101000100 1010100001001001101011000 1110111000101100100000101 0110101001011010000100111
26	11010011110010010110000010 1110111011011111000011011 00101110101111001110001000 111001001110000000000011110 01010000101011111111000011 00100110100110011001000100 00010111111011010111100001 00100110110100000110011111 1111111100100000000001000110 11100011100110011011100011 00000111100110010101100001 110110101101100000000001110 11011001000000111000100110 11010011010000100100110000 01100001101001101101111100 01110011100000101011100110 00101011101010101001011001 10110001010101111101001010 00111111111110010101100011 10010001101100111010110101	01011010000011100100001101 10000001011110101001110001 00000100101001110001100111 10011000010001101101101011 11111010100100000001110001 00000111000011100001011011 10010010011101110110010011 00010001010011100110001100 10111110000110101000101000 00000010110111100000001111 10100011100010010110001010 00111111010011111001110110 11100010010101100000000001 00101101011101100111100111 11110101111010111111000111 10110110010110010111000100 10010010111110110110010100 00001101001011011000101001 00101101001101011000000100 11001001110101010011100111
27	1010101000110101001000000100 0000000101001010011001001011 100111111110101110100010000 1011101111111110011000001011 1001011101110101100110000 11 1011000100111011011111111100 1011110100010010101010110 01 0010010110000100010011011 00 0000110100110111001000101 00 1001101110100111001011011 00 0101111100100001001001110 10 1100111010011000000000110 10 1010011000101000100010101 10 1000100011001100100010000 11 0011000101110100000111010 10 0100000111010110010010010 11 0010110000000110011101111 110 0010110111100001011100100 11 0011110001001001110011101 11 0111010100100110010001010 01	000011100010111100110100001 1010111101011000111111111101 100010111000111011001110100 1011111100111101001010000 01 0110100110001100111101101 01 0101001111110101100011001 11 1000011111010110111101110 11 0100111111011010100001000 00 0001101000101000110100001 11 0100001110110111111010000 11 1011011010011101111001010 10 0001011100110001111110000 00 0000000001011000010110110 00 1100110010101010100001110 10 1011100000011010011101100 10 1110111111000100010000100 11 1100000000111001000010101 01 0100101000011011001001000 01 1001101110110111101100011 01 1001101111111110000000110 110
28	01001010100110010101011001 01 00110111111111010100101111 00 01001000110001110110101000 00 00011010111101001001011010 00 11000101001101010101111111 01 11101111100101101101101111 10 01100111011101111000111101 11 11010011010100101111001101 11 11111111110111011111110010 01 01001001100010110101001000 00 10111001001111100011001001 10 01010011010001110001010000 11 10011010110010110111011101 10 11011010011100100000100010 01 00011101000000110000101101 10 00011001010011001001011100 11 10000101110101110010100001 01 00111100100001011101101100 11 00000010000111011001010000 11 11100111001010001011111101 10	11000011110010010100000011 01 00110111111010001001011010 11 01110111101001101011010110 10 10110110100110111000011001 00 00001100000001011010101000 011 11100100110100000111111100 01 10111000011010001010011111 00 00000010100001111111011010 00 10101000001100001100010101 10 11000101011011101001011110 11 10010101111010100001101000 01 10011101100111110011011111 11 10101100111111000101101110 10 00100100110000000101011001 11 11011011100111000010100011 11 01110000100001011111000000 01 01110100001110101110011101 10 00001101010100111110010101 10 11011111000000101001111000 00 01010100011101100000100110 00
29	000110101011110000100100111 11 111101011100101110110001000 11 011000000110011011111010010 01 000111100000000000110000101 110 110111110000011110010110111 00 101100011010111000111011001 01 111111011000000110000110011 00 110101111010100010011110110 00 010011100110100101101011001 01 101001101100010100000100001 01 100100011000011001111101111 11 011111101110011111001101001 00 110110000111010101100000110 00 100101111011000001101011101 01 001101111100110110001110010 01 100110001001101101000101011 10 011110011000110100111001110 01 110000011100011110111100101 10 000010011000011000110110001 11 110110101001010111000110111 01	100001000000110000101011110 10 110110100100010100001011001 11 101011011001010000000111111 10 110011000001010011001010000 00 111101111111011111101100011 00 001110110101010110011011001 00 110010101010010110001100011 00 111110100001011001000000011 00 110110011100010011101010100 10 000101011000010100011000011 00 001000010001000000000100010 01 010111010010101101111000111 10 001001011000010111111101010 11 110010111001001111101011100 00 100110101000000010010110110 00 010011111000111000011100001 01 000000011110111100111110010 11 011111100100000100011011110 11 111000011001000100111100001 01 001001111111110100011100010 11
30	01100110001011111000101001110 1 11001011101001010110000101000 0	10000011110110010111010000011 1 01100100110000110010001100010 1

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