

Implementation of Quine-McCluskey

수업명 : 디지털논리신호

과제 이름 : Implementation of Quine McCluskey

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A. Problem statement (15)

콰인-맥클러스키 알고리즘은 부울식을 단순화하는 알고리즘이다. 카르노맵 알고리즘에 비해 조금 복잡하지만, 더 많은 변수를 다룰 수 있다.

구현은 크게 PI(Prime Implicant)를 찾고, 그 중에서 EPI(Essential PI)를 찾고, 구한 SOP의 트랜지스터 개수를 구하는 세 단계로 나뉘어진다.

첫 번째는 PI를 찾는 것인데, Implicant Table을 활용하여 구할 수 있다. 먼저 주어진 입력들을 1의 개수를 통해 분류하여 그룹짓는다. 그리고 각 그룹에서 해밍거리가 1만큼 차이 나는 것이 있는지 체크하고, 만약 1만큼 차이 난다면 해당 자리에 '-'로 표시하여 두 숫자를 하나로 묶는다. 이를 반복하였을 때 서로 묶이지 않는 것이 PI이다.

두 번째로 EPI를 찾기 위해서, PI들과 True인 minterm들을 각각 table의 행과 열의 헤더로 활용한다. PI가 커버할 수 있는 minterm들에 대해서 교점을 찍듯이 표시하면 EPI를 고를 준비가 된 것이다. 만약 PI가 유일한 열이 있다면, 다시 말해 해당 minterm을 표현할 PI가 유일하다면, 그 PI를 EPI로 선택하고 해당 PI로 표현할 수 있는 minterm들을 추가로 지운다. 이를 반복하면 EPI를 구할 수 있는데, 문제는 유일한 열이 없을 때 발생한다. 이를 해결하기 위해서는 부울 논리를 활용한 패드릭의 방법이 있고, 나는 그리디한 방법을 사용하였다.

세 번째로 구한 SOP에 필요한 트랜지스터를 구하는 것은 2단계의 논리회로라는 점과 inverter, AND, OR 세 가지 게이트만 활용한다는 제한이 있어 단순해졌다. 인버터는 2개가 필요한데, 각 변수별로 필요한지 아닌지 세면 된다. NAND와 NOR의 경우 CMOS를 통해 인풋의 두배만큼의 트랜지스터를 사용해 구현할 수 있으니 AND와 OR은 인버터를 추가하여 구현할 수 있다. 따라서 AND의 경우 대시로 표시하지 않은 1과 0의 값만큼 input이 필요한데, 인풋의 두배에 2를 더한 만큼 사용하여 구할 수 있다. OR의 경우 EPI의 개수가 인풋의 개수이다.

B. Your algorithm with pseudo code and flow chart (30)

```
class minTerm {
public :
    char value;
    string binary;
    bool isCmbnd;
};

int bincmp(string &bin1, string &bin2) {
    for (int i = 0; i < bin1.length(); i++) {
        if (bin1[i] != bin2[i]) {
            cnt++; // 다른 비트 개수
            pos = i; // 위치 저장
        }
    }
    return (cnt == 1) ? pos : -1; // 다른 게 하나면 위치 반환, or -1 반환
}

bool binMatch(string &bin1, string &bin2) {
    for (int i = 0; i < bin1.length(); i++) {
        if (bin1[i] == '-' || bin2[i] == '-') continue; // '-'는 0과 1 둘다 포함, match
        if (bin1[i] != bin2[i]) return false; // 비트가 다르면 false
    }
    return true;
}

int getNumTrans(set<string> &EPIs, int b_len) {
    int trans_num = 0; // 트랜지스터 개수

    int Or = EPIs.size(); // EPI의 개수가 OR의 input 개수
    if (Or > 1) // 인풋 개수는 항상 2보다 큼
        trans_num += (Or << 1) + 2; // (NOR(input * 2) + inverter(2) => OR)
    for (auto &k : EPIs) {
        int cnt_dash = 0; // '-' 대신 하나마다 AND input 하나씩 감소
        int pos_zero = 0; // 인버터를 위해 0이 있는 자리 계산
        for (int i = 0; i < b_len; i++) {
            if (k[i] == '-') cnt_dash++;
            if (k[i] == '0') pos_zero += (1 << i); // 0의 위치 정보를 2진법에서 10진법으로 전환
        }
        And = b_len - cnt_dash;
        if (And > 1) // 인풋 개수는 항상 2보다 큼
            trans_num += (And << 1) + 2; // (NAND(input * 2) + inverter(2) => AND)

        Not |= pos_zero; // 0이 있는 위치들을 합집합연산(각 인덱스별로 0이 있는지 없는지)
    }
    while (Not) {
        if (Not % 2 == 1) trans_num += 2; // 찾은 0 한개마다 인버터 하나씩(트랜지스터 두개씩)
        Not >>= 1;
    }
}
```

```

    return trans_num;
}

int main(int argc, char *argv[]) {
    int b_len; // 비트 길이
    fin >> b_len;
    vector<minTerm> MT[b_len+1]; // minterms
    vector<string> PIs; // Prime Implicants
    vector<string> trueMT; // true minterms

    minTerm init; int ones; // mt 벡터 초기화
    while (!fin.eof()) {
        fin >> init.value >> init.binary;
        if (init.value == 'm') trueMT.push_back(init.binary); // true minterm 저장
        ones = count(init.binary.begin(), init.binary.end(), '1'); // 1 개수 세기
        MT[ones].push_back(init); // 개수별로 정리
    }

    while (2021202033) {
        bool brk = 1; // 루프 탈출 플래그. 더 이상 합칠 게 없으면 1로 유지. 합쳐지면 0.
        for (int i = 0; i < b_len; i++) {
            for (auto &k : MT[i]) {
                for (auto &k2 : MT[i+1]) { // 해밍디스턴스 1인 그룹
                    int pos;
                    if ((pos = bincmp(k.binary, k2.binary)) != -1) { // 비트가 하나만 다를 때 위치(인덱스) 반환, or -1
                        brk = 0; // 루프 한번 더
                        k.isCmbnd = true; k2.isCmbnd = true; // 사용 표시
                        string combined(k.binary);
                        combined[pos] = '-'; // 겹치는 부분 '-' 표시 -> 합치기
                        uniq.emplace(combined); // 합친 표현 저장
                    }
                }
            }
        }
        for (int i = 0; i < b_len+1; i++) {
            for (auto &k : MT[i]) {
                if (k.isCmbnd == false)
                    PIs.push_back(k.binary); // PI 저장
            }
            for (auto &k : uniq) // 저장해놓은 비트들
                if (count(k.begin(), k.end(), '1') == i) MT[i].push_back(k); // 새로 만든 것들 다시 1개수 순으로 그룹화하여 저장
        }
        if (brk) break;
        b_len--;
    }

    set<string> EPIs; // Essential PIs
    vector<int> table; // Essential PI를 찾기 위한 표. int형 정수를 통해 비트로 표현.(메모리, 성능)

    for (int i = 0; i < trueMT.size(); i++) { // 열을 먼저 확인하기 위함
        int col = 0;
        int cnt = 0; // 열에 PI가 얼마나 있는지 count
        int pos = -1; // PI가 하나일 때 EPI로 사용할 수 있게 위치 저장
        for (int j = 0; j < PIs.size(); j++) {
            if (binMatch(trueMT[i], PIs[j])) {
                col |= (1 << j); // 해당 비트에 1로 표시하기
                cnt++;
                pos = j;
            }
        }
        if (cnt == 1) { // 열에 PI 하나 -> Essential PI
            EPIs.emplace(PIs[pos]);
            trueMT.erase(trueMT.begin()+i--); // 해당 true minterm은 필요 없어짐.
            for (int t = 0; t < i; t++) {
                if (table[t] & (1 << pos)) {
                    table.erase(table.begin() + t); // 방금 선택한 PI가 포함하는 범위. 해당 열 삭제
                    trueMT.erase(trueMT.begin()+t--); i--;
                }
            }
        }
        else table.push_back(col);
    }

    while(!trueMT.empty()) { // EPI 다 못찾은 경우
        int maxMt = 0; // 한 행당 minterm의 최대 개수
        int maxpos = -1; // minterm이 가장 많은 행의 위치

        if (trueMT.size() < 2) {
            if (trueMT.empty()) break; // 다 찾은 경우
            for (int i = 0; i < PIs.size(); i++) { // 하나만 남은 경우
                if (table[0] & (1 << i)) {
                    EPIs.emplace(PIs[i]);
                    break;
                }
            }
        }
    }
}

```

```

    }
}

for (int i = 0; i < PIs.size(); i++) { // maxMT, maxpos 찾기
    int cnt = 0;
    for (int j = 0; j < trueMT.size(); j++) {
        if (table[j] & (1 << i)) cnt++; // MT가 있으면 카운트
    }
    if (maxMt < cnt) {
        maxMt = cnt;
        maxpos = i;
    }
}
EPIs.emplace(PIs[maxpos]); // 찾은 행 EPI로 저장
for (int i = 0; i < trueMT.size(); i++) { // 해당 PI가 커버하는 minterm들 삭제
    if (table[i] & (1 << maxpos)) {
        table.erase(table.begin() + i);
        trueMT.erase(trueMT.begin()+i--);
    }
}

if (trueMT.size() < 2) {
    if (trueMT.empty()) break; // 다 찾은 경우
    for (int i = 0; i < PIs.size(); i++) { // 하나만 남은 경우
        if (table[0] & (1 << i)) {
            EPIs.emplace(PIs[i]);
            break;
        }
    }
}

if (trueMT.empty()) break; // minterm 개수가 최대인 행 접근으로 해결된 경우

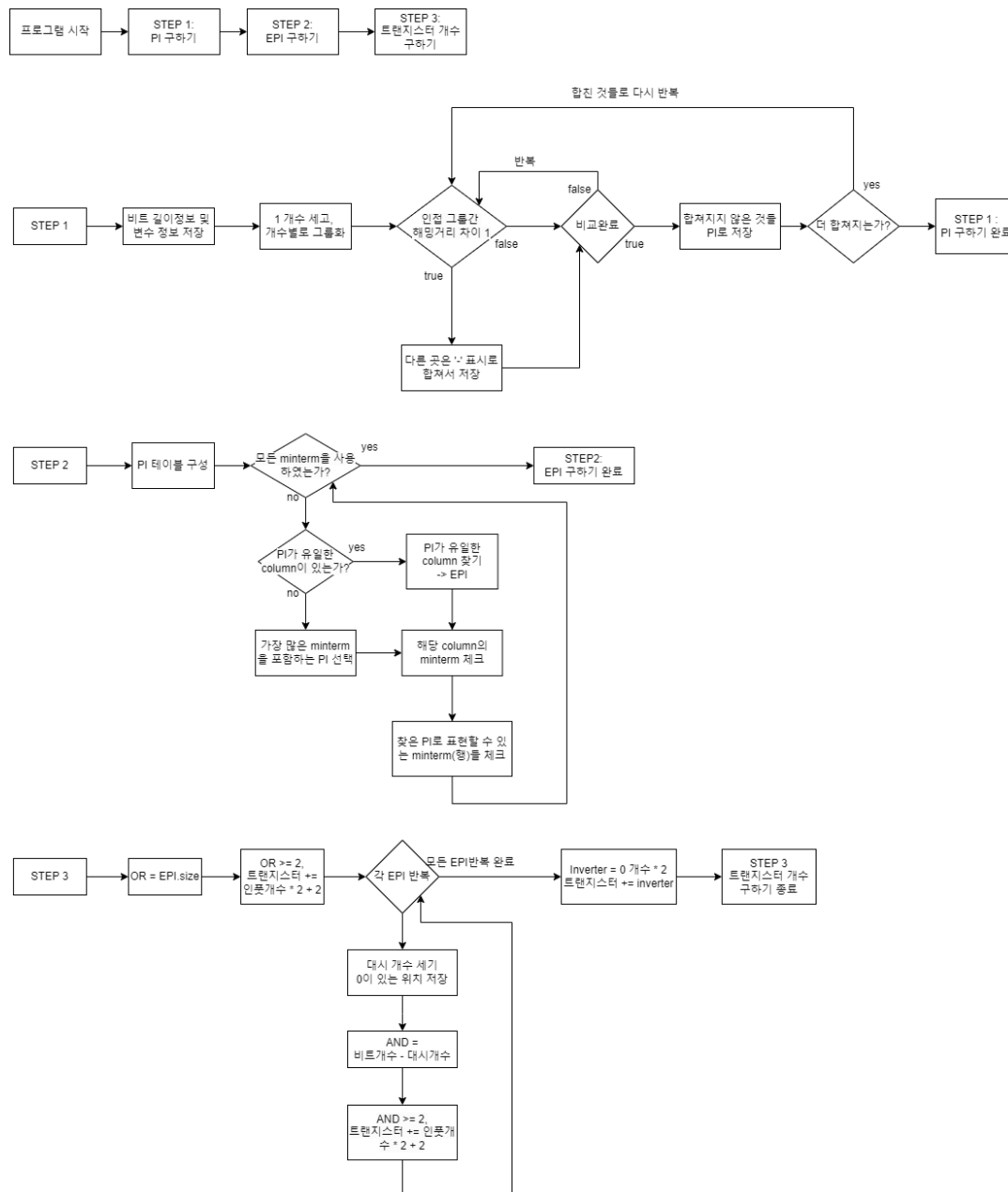
for (int i = 0; i < trueMT.size(); i++) { // 다시 한 번 유일 minterm이 있는 열 확인
    int cnt = 0;
    int pos = -1;
    for (int j = 0; j < PIs.size(); j++) {
        if (table[i] & (1 << j)) {
            cnt++;
            pos = j;
        }
    }
    if (cnt == 1) {
        EPIs.emplace(PIs[pos]);
        trueMT.erase(trueMT.begin()+i--); // 해당 true minterm은 필요 없어짐.
        if (!trueMT.empty()) {
            for (int t = 0; t < trueMT.size(); t++) {
                if (table[t] & (1 << pos)) {
                    table[t] = 0; // 방금 선택한 PI가 포함하는 범위. 해당 열 삭제
                    trueMT.erase(trueMT.begin()+t--); i--;
                }
            }
        }
    }
}

for (auto &k : EPIs)
    fout << k << '\n';
fout << "\nCost(# of transistors): " << getNumTrans(EPIs, PIs[0].length());

fin.close();
fout.close()

```

슈도코드



플로우차트

```

PS C:\Users\sungm\source\repos\QM\x64\Debug> .\QMChk.exe .\QM.exe
Automatic Process Memory Checker
=====
Trying to create child process: .\QM.exe
Running: .\QM.exe
Please wait....

RUN REPORT
=====
Peak page size: 1 MiB (1175552 B)
Peak working set size: 6 MiB (6393856 B)
Runtime: 12 msec

```

프로그램 적용 화면

```

PS C:\Users\sungm\source\repos\2021202033_Project> .\QMChk.exe .\QM.exe
Automatic Process Memory Checker
=====
Trying to create child process: .\QM.exe
Running: .\QM.exe
Please wait....

RUN REPORT
=====
Peak page size: 1 MiB (1761280 B)
Peak working set size: 6 MiB (6680576 B)
Runtime: 250 msec
PS C:\Users\sungm\source\repos\2021202033_Project>

```

100비트, 1000 line으로 테스트한 결과

C. Verification strategy & corresponding examples with explanation (50)

- PI 구하기
 - minterm 클래스를 만들어 값을 저장하고, merge 여부를 체크했다. merge되지 않은 것은 PI로 추가하였다. 예를 들어 0000과 0001을 비교한다면 서로 다른 비트가 하나기 때문에 isCmbnd 변수를 true로 저장해주고, 모든 경우의 수를 반복한 뒤 isCmbnd 변수가 false인 것을 PI로 추가하였다.
- EPI 구하기
 - 테이블을 인트형 배열로 사용하였고, 인트형 정수를 32비트 숫자로 생각하여 가로로 최대 32개의 너비를 가지는 2차원 배열을 구성하였다.
 - 행 by 행으로 입력받는 것보다 열 by 열로 입력받으면서, 동시에 해당 열의 PI의 cnt와 위치정보를 기록하였다. 그렇게 하여 유일한 PI가 발견되면 바로 EPI로 저장하고, 해당 minterm과 해당 PI가 포함하는, 그 이전까지 나온 것들을 삭제하였다.
 - 강의자료의 케이스를 활용해 예시를 들면 다음과 같다.

PI \ minterm	0100	0101	0110	1001	1010
PI1. 1010					
PI2. 0-00	x				
PI3. 1-01					
PI4. 01--	x	x	x		
PI5. -1-1		x			

- 0100과 0101의 경우 유일한 minterm을 가지고 있기 때문에 계속 입력받고, 0110에서 minterm이 유일한 것을 발견하였다. 따라서 0110을 처리하고, 해당 PI로 표현할 수 있는 0101과 0100도 뒤로 돌아가 처리해준다.

PI \ minterm	0100	0101	0110	1001	1010
PI1. 1010					x
PI2. 0-00					
PI3. 1-01				x	
PI4. 01-- V	V	V	V		
PI5. -1-1					

- 그런 다음 1001과 1010을 입력받는데, 둘 모두 유일한 PI를 가지므로 체크한다. 따라서 PI1,3,4를 최종적으로 EPI로 선택하게 된다.
- EPI 구하기 - PI가 유일한 열이 없을 때
 - PI가 유일한 열이 없다는 것은, 무엇을 골라도 성립하기는 한다는 것이다. 그러나 SOP의 2단계 논리회로를 구성해야 하므로, 트랜지스터의 개수를 줄이기 위해 가장 간단한 SOP를 찾아야 한다.

- 경우의 수가 많지 않으니 백트래킹으로 모든 경우의 수를 비교하려고 하다가, 속도 면에서 보너스 점수를 노리기 위해 그리디한 접근 방법을 떠올렸다.
- 그 방법은 minterm을 가장 많이 포함하는 행(PI)을 선택하는 것이다. minterm을 포함하는 개수가 모든 PI에서 같다면 첫번째로 나온 것을 선택한다. minterm을 많이 포함하는 것은 '-'(대시)의 숫자가 많을 확률이 높고, 그렇다면 SOP에서 AND의 인풋 개수도 감소한다.
- 행을 통한 접근을 한 뒤엔, 유일한 minterm을 가진 열이 생겼는지 확인하여 열을 통해 접근할지 행을 통해 접근할지 결정한다.
- 아래에 제시할 TC를 통해 예시를 들어보면 다음과 같다. 해당 예시에서는 모든 PI의 대시 개수가 같으므로 대시 개수는 고려하지 않는다.

$$F(a,b,c) = \sum m(0,1,2,5,6,7)$$

PI \ minterm	0001	0010	0101	0111	1001	1111
PI1. 00-	x	x				
PI2. 0-0	x		x			
PI3. -01		x		x		
PI4. -10			x		x	
PI5. 1-1				x		x
PI6. 11-					x	x

- 해당 케이스의 PI를 구하여 table에 옮기면 위 표와 같이 되는데, 유일한 열이 하나도 없다. 그렇다고 차례대로 선택하게 되면 PI를 위에서부터 총 다섯 개 사용하게 된다.
- 위에서 언급한대로 행을 통해 접근한다면, PI1번에서 minterm의 개수가 최대가 된 뒤에 유지가 되므로, PI1번을 선택한다. 그런 다음 PI1이 포함하는 minterm 0001, 0010을 소거한다. 그럼 다음과 같은 상태가 될 것이다.

PI \ minterm	0001	0010	0101	0111	1001	1111
PI1. 00- V	V	V				
PI2. 0-0			x			
PI3. -01				x		
PI4. -10			x		x	
PI5. 1-1				x		x
PI6. 11-					x	x

- 유일한 minterm의 열이 없기 때문에 다시 한 번 행을 통해 접근한다.
- 만약 순차적으로 접근했다면 여기서 PI2를 선택했겠지만, PI2는 현재 포함하는 minterm의 개수가 한 개이고, PI3도 마찬가지이므로, PI4를 선택하게 된다. 선택하고 나면 다음과 같은 상태가 된다.

PI \ minterm	0001	0010	0101	0111	1001	1111
PI1. 00- V	V	V				
PI2. 0-0						
PI3. -01				x		
PI4. -10 V			V		V	
PI5. 1-1				x		x
PI6. 11-						x

- 이제 다음 번에는 minterm이 두개로 가장 많은 PI5를 EPI로 선택하게 되고 모든 minterm을 골랐으니 다음 단계로 넘어가게 된다.

• 트랜지스터 구하기

- OR과 AND의 경우 인풋개수가 1이면 성립하지 않으므로 추가하지 않도록 하였다. 예를 들어 ---1는 D이므로 AND연산할 필요가 없다.

- 0이 있는 곳의 위치를 비트로 표시하였다. EPI 각각의 비트를 돌며 비트마스킹을 하여 0의 위치를 찾았고, 이를 Not 인자에 합집합 연산하면서 추가하였다. 예를 들어 00--, 0--1, 1--0이 있다면 0의 위치를 1101과 같이 표시하여 inverter가 총 세 개의 변수에 사용된다는 것을 표현한다.

D. A testcase that you think it is very hard to solve (5)

- multiple EPI case

3
m 000
m 001
m 010
m 101
m 110
m 111

결과 :

-01
0-0
11-

Cost(# of transistors): 32

- 큰 수(100비트, 1000line testcase)

100
m 00011010001000010101110000000111100000011110110011001010000111101111100011001100101011110001101010
d 001001110101001100011011110001000101011000011110100101011100010111000110010111111111011000100001111
d 1000100110111001011110110110010011101101111001101001010010101000010111000011010001010010111110011
d 1010000100011110110011100110011011100101000111000101100101111010101011101000101100001001110110010
m
1000101010011000011101100110101111100001010110110110010100111000001010011110010110100100111011011001
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Cost(# of transistors): 72958