

01204211 Discrete Mathematics  
Lecture 5: Proof techniques 2

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# Proof techniques

In this lecture, we will focus on two other proof techniques.

- ▶ Proofs by contradiction
- ▶ Proofs by cases

## Proofs by contradiction

We want to prove that proposition  $P$  is true. To do so, we first assume that  $P$  is false, and show that this logically leads to a contradiction. This means that it is impossible for  $P$  to be false; hence,  $P$  has to be true. This is called a proof by contradiction or *reductio ad absurdum*.

### Direct proofs

#### **Theorem:**

$P$

#### **Proof.**

We use prove by contradiction.

Assume  $\neg P$ .

... (then show that  $R$  and  $\neg R$  follows from  $\neg P$ )

This is a contradiction. Therefore,  $P$  must be true.



## Example 1 (1)

### Theorem 1

$\sqrt{2}$  is irrational.

### Proof.

We prove by contradiction. Assume that the theorem is false, i.e., assume that  $\sqrt{2}$  is rational.

Therefore, there exists a pair of positive integers  $a$  and  $b$  such that  $\sqrt{2} = a/b$ . Let's choose the pair  $a$  and  $b$  such that  $b$  is minimum.

In this case,  $a$  and  $b$  share no common factors.

Let's square both terms. We get  $2 = a^2/b^2$ , or

$$a^2 = 2b^2.$$

(cont. in next slide)



## Example 1 (2)

### Proof. (cont.)

By definition, we know that  $a^2$  is an even number. From a theorem from last time, we know that  $a$  must also be an even number.

Again by definition, there exists integer  $k$  such that  $a = 2k$ . We then obtain

$$2b^2 = (2k)^2 = 4k^2,$$

i.e.,  $b^2 = 2k^2$ . This implies that  $b^2$  is an even number. Again, this means that  $b$  must be an even number.

**[quick check]** Do you see that we are arriving at a contradiction here?

(cont. in the next slide)



## Example 1 (3)

### Proof. (cont.)

Since  $a$  and  $b$  are both even numbers, they share 2 as a common factor.

This contradicts the fact that we choose the pair  $a$  and  $b$  that share no common factor.

Therefore,  $\sqrt{2}$  must be irrational.



## Proofs by cases

- ▶ The last proof technique that we shall discuss is closely related to proofs by exhaustion we tried before.
- ▶ Sometimes when we want to prove a statement, there are many possible cases. Also, we might not know which cases are true.
- ▶ We might still be able to prove the statement if we can show that the statement is true in every case.

## Example 2 (1)

### Theorem 2

*Suppose that I have 3 pairs of socks: one pair in gray, one pair in white, and one pair in black. If I pick any 4 socks, I will have at least one pair of the same color.*

If we want to prove by exhaustion, we will have to consider all 15 cases.

### Proof.

Let's split the process of picking 4 socks into 2 steps. First, pick 3 socks, then pick the last sock.

After we pick the first 3 socks. There are 2 possible cases: either I have a pair of socks with the same color, or I do not have such a pair. We shall consider each case separately.

(cont. in the next slide)





## Example 2 (1)

### Proof. (cont.)

- ▶ **Case 1:** *I have a pair of socks with the same color.*

In this case, the theorem is true.

- ▶ **Case 2:** *I do not have a pair of socks with the same color.*

In this case, since I have 3 colors and 3 socks, I must have one sock for each color. Now, after we pick the last sock, whatever color the last one is, we have a color-matching sock in our first 3 socks. Therefore, the theorem is also true in this case.

Since these two cases cover all possibilities, we conclude that the theorem is true. □

## Proofs by cases in propositional logic

In propositional logic, the following describe a proof by cases.

$$\begin{array}{l} P \vee Q \vee R \\ P \Rightarrow S \\ Q \Rightarrow S \\ R \Rightarrow S \\ \hline S \end{array}$$

Sometimes, when we have 2 cases, we also see:

$$\begin{array}{l} P \vee \neg P \\ P \Rightarrow S \\ \neg P \Rightarrow S \\ \hline S \end{array}$$

Note that we can leave  $P \vee \neg P$  out, because it is always true.