

## 1. Logik

Logik ist eine Lehre des vernünftigen Schlussfolgerns. Man unterscheidet Aussagenlogik und Prädikatenlogik.

### 1.1. Logische Aussagen und Verknüpfungen

**Aussagenlogik** – eine Lehre von Aussagen und ihren Verknüpfungen.

**Definition 1.1** Eine Aussage ist ein Satz, der entweder wahr (engl. true) oder falsch (engl. false) ist. Es gilt das Prinzip des ausgeschlossenen Dritten: ein Drittes gibt es nicht.

#### Aussagen

$A \wedge B$ : Konjunktion (A und B).  
 $A \vee B$ : Disjunktion (A oder B).  
 $A \rightarrow B \equiv \neg(A \wedge \neg B)$ : Implikation (wenn A, dann B).  
 $A \leftrightarrow B \equiv (\neg(A \vee B)) \vee (\neg(\neg A \vee \neg B))$ : Äquivalenz (A genau dann, wenn B).  
 $A \downarrow B \equiv \neg(A \wedge B)$ : Scheffers-Operator (NAND). (J.  
 $A \uparrow B \equiv \neg(A \vee B)$ : Peirce-Operator (NOR). (J.  
 $A \oplus B \equiv \neg(A \leftrightarrow B) \equiv \neg((\neg A \vee B) \wedge (\neg B \vee A))$ : Exklusives ODER (XOR). (J.)

**Satz 1.1** (Hing an regnet, dann ist die Straße nass) wird mit Hilfe von zwei atomaren Aussagen und der Implikation formuliert:

A: „Es regnet“, B: „Die Straße ist nass“,  $A \rightarrow B$

#### Wahrheitswerte der Verknüpfungen:

A	B	$A \wedge B$	$A \vee B$	$A \rightarrow B$	$A \leftrightarrow B$
0	0	0	0	1	1
0	1	0	1	1	0
1	0	0	1	0	0
1	1	1	1	1	1

A	B	$A \downarrow B$	$A \uparrow B$	$A \oplus B$
0	0	1	1	0
0	1	1	0	1
1	0	1	0	1
1	1	0	1	0

**Lemma 1.1** Es seien A und B Aussagen. Für die NAND- und NOR-Verknüpfung lassen sich die Negation, Konjunktion und Disjunktion wie folgt ausdrücken:

1. Negation:  $\neg A \equiv A \downarrow A \equiv A \uparrow A$
2. Konjunktion:  $A \wedge B \equiv (A \downarrow B) \downarrow (A \downarrow B) \equiv (A \uparrow B) \uparrow (A \uparrow B)$
3. Disjunktion:  $A \vee B \equiv (A \downarrow A) \downarrow (B \downarrow B) \equiv (A \uparrow A) \uparrow (B \uparrow B)$

#### Logische Formeln

**Definition 1.2** Sei  $F$  eine logische Formel (Verknüpfung mehrerer Aussagen). Für jede Formel  $F$  der Aussagenlogik gilt es 3 Möglichkeiten:

- a)  $F$  heißt **erfüllbar**, falls es mindestens eine Kombination der Aussagenvariablen gibt, für die Formel  $F$  wahr ist.
- b)  $F$  heißt **Tautologie** (oder allgemein gültig), falls für alle Kombinationen der Aussagenvariablen die Formel  $F$  wahr ist.
- c)  $F$  heißt **Kontradiktion** (Widerspruch), falls für alle Kombinationen der Aussagenvariablen die Formel  $F$  falsch ist.

#### Gesetze der Aussagenlogik:

**Satz 1.1** Es sei A eine Aussage, dann gilt:

- a)  $A \wedge B \equiv B \wedge A$
- b)  $A \wedge (B \wedge C) \equiv (A \wedge B) \wedge C$
- c)  $\neg\neg A \equiv A$  (doppelte Negation)
- d)  $A \vee \neg A \equiv 1$
- e)  $A \wedge \neg A \equiv 0$
- f)  $A \vee A \equiv A$
- g)  $A \wedge A \equiv A$

**Satz 1.2** Es sei A, B und C Aussagen, dann gilt:

- Kommutativgesetz:**  $A \wedge B \equiv B \wedge A, A \vee B \equiv B \vee A$
- Assoziativgesetz:**  $A \wedge (B \wedge C) \equiv (A \wedge B) \wedge C$   
 $A \vee (B \vee C) \equiv (A \vee B) \vee C$
- Distributivgesetz:**  $A \wedge (B \vee C) \equiv (A \wedge B) \vee (A \wedge C)$   
 $A \vee (B \wedge C) \equiv (A \vee B) \wedge (A \vee C)$
- De-Morganische Gesetze:**  
 $\neg(A \wedge B) \equiv (\neg A) \vee (\neg B), \neg(A \vee B) \equiv (\neg A) \wedge (\neg B)$
- Gesetz der Kontraposition:**  
 $A \rightarrow B \equiv (\neg B) \rightarrow (\neg A)$
- Weitere Gesetze:**  
 $A \rightarrow B \equiv (\neg A) \vee B, A \leftrightarrow B \equiv (A \rightarrow B) \wedge (B \rightarrow A)$

## 1.2. Boolesche Algebras - Schaltalgebra

Schaltalgebra der Verknüpfungen:

Komplement (Negation):  $\neg a \equiv \bar{a}$

Konjunktion:  $a \wedge b \equiv a \cdot b$

Disjunktion:  $a \vee b \equiv a + b$

**Bezeichnung 1.1** Alle Gesetze aus dem Satz 1.1 gelten auch für die booleschen Variablen (mit geändertem Schreibweise!!!)

**Definition 1.3** Jede elementare Aussage oder boolesche Variable ist ein Boolescher Term. Ein  $n$ -stelliger Boolescher Term  $p(x_1, x_2, \dots, x_n)$  besteht aus den Werten 0, 1 oder den Booleschen Variablen  $x_1, x_2, \dots, x_n$ , sowie sämtlichen daraus mit den eingeführten Verknüpfungen  $(\neg, \wedge, \vee)$  konstruierten Ausdrücken.

**Satz 1.2** Der Boolesche Term:

$$p(x, y, z) = (\neg x y) + (\neg x y z) + (x y z) + (x y z) + (x y z)$$

**Definition 1.4** Die Komplexität eines Booleschen Terms kann man als die Anzahl der in ihm verwendeten binären Operationen  $\neg$  und  $\wedge, \vee$  definieren.

**Definition 1.5** Einen Booleschen Term mit minimaler Komplexität nennt man **Minimalterm** des Booleschen Terms.

## 1.3. Normalformen

DNF bzw. KNF: disjunktive bzw. konjunktive Normalform

**Definition 1.4** (1) Ein **Literal**  $x$  ist ein Boolescher Term, der entweder aus einer atomaren Booleschen Variablen  $x$  oder ihrem Komplement  $\neg x$  besteht.

(2) Ein  $n$ -stelliger Boolescher Term der Form  $x_1 \wedge x_2 \wedge \dots \wedge x_n$  heißt **konjunktiver Minimalterm**, wenn  $x_j = x_j$  oder  $x_j = \neg x_j$  für  $j = \{1, \dots, n\}$  gilt, also der Term das Produkt der  $n$  Literale von  $x_j$  ist.

(3) Ein  $n$ -stelliger Boolescher Term der Form  $x_1 \vee x_2 \vee \dots \vee x_n$  heißt **disjunktiver Minimalterm**, wenn  $x_j = x_j$  oder  $x_j = \neg x_j$  für  $j = \{1, \dots, n\}$  gilt, also der Term die Summe der  $n$  Literale von  $x_j$  ist.

(4) Ein boolescher Term befindet sich in DNF, wenn er ausschließlich aus Disjunktionen von konjunktiven Minimaltermen besteht.

$$p(x, y) = (x \wedge y) + (x \wedge \neg y)$$

(5) Ein boolescher Term befindet sich in KNF, wenn er ausschließlich aus Konjunktionen von disjunktiven Minimaltermen besteht.

$$q(x, y) = (x + y) \cdot (x + \neg y)$$

## 1.4. Algorithmen zur Erstellung der DNF oder KNF mit Hilfe der Wahrheitstabelle:

**DNF:**

1. Wähle Zeilen mit  $p = 1$ .
2. Anzahl **Miniterme** = Anzahl der Zeilen mit  $p = 1$ , verbinde die Miniterme mit " $\vee$ ".
3. Beschreibe, wenn die Miniterme erfüllt sind für  $x = 1$  schreibe  $x$ , für  $x = 0$  schreibe  $\neg x$ .

**KNF:**

1. Wähle Zeilen mit  $p = 0$ .
2. Anzahl **Maxterme** = Anzahl der Zeilen mit  $p = 0$ , verbinde die Maxterme mit " $\wedge$ ".
3. Beschreibe, wenn die Maxterme erfüllt sind für  $x = 0$  schreibe  $x$ , für  $x = 1$  schreibe  $\neg x$ .

## 1.5. Prädikatenlogik und Quantoren

**Definition 1.7** Ein **Prädikat** ist ein Satz (bzw. Formel)  $A(x)$ , der (bzw. die) eine oder mehrere Variablen enthält  $A(x_1, x_2, \dots, x_n)$ , die (bzw. die) nach der Ersetzung der Variablen durch konkrete Objekte zu einer Aussage wird.

**Definition 1.8** Mit Hilfe von Quantoren  $(\forall, \exists, \neg)$  können aus Prädikaten neue Aussagen gebildet werden:

- für alle  $x$  gilt  $A(x)$ :  $\forall x : A(x)$  (Allquantor)
- es gibt mind. ein  $x$ , für das  $A(x)$  gilt:  $\exists x : A(x)$  (Existenzquantor)
- es gibt genau ein  $x$ , für das  $A(x)$  gilt:  $\exists! x : A(x)$

## 2. Grundbegriffe der Mengenlehre und Kombinatorik

### 2.1. Mengenbegriff, Darstellung von Mengen

**Definition 2.1** (Cantor, 1879)

„Unter einer **Menge** verstehen wir jede Zusammenfassung  $M$  von bestimmten wohl unterschiedenen Objekten  $x$  unserer Anschauung oder unseres Denkens (welche die Elemente von  $M$  genannt werden) zu einem Ganzen.“

#### Zahlenbereiche:

$\mathbb{N} = 1, 2, 3, \dots$  = Menge der natürlichen Zahlen

$\mathbb{N}_0 = 0, 1, 2, 3, \dots = \mathbb{N} \cup \{0\}$  = erweiterte Menge der natürlichen Zahlen

$\mathbb{Z} = \dots, -3, -2, -1, 0, 1, 2, 3, \dots$  = Menge der ganzen Zahlen

# Einführung In Die Grundlagen Der Mathematik Theorie Der Berechenbarkeit Mathematische Logik Mengenlehre

**AN Whitehead**



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