

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).
 $A \Leftrightarrow B \equiv (\neg(A \wedge \neg B)) \wedge (\neg(\neg A \wedge B))$: Äquivalenz (A genau dann, wenn B).
 $A \downarrow B \equiv \neg(A \wedge B)$: Scheffers-Operator (NAND). (1.
 $A \uparrow B \equiv \neg(A \vee B)$: Peirce-Operator (NOR). (2.)
 $A \oplus B \equiv \neg(A \Leftrightarrow B) \equiv \neg((\neg A \vee B) \wedge (A \vee \neg B))$: Exklusives ODER (XOR, 3.)

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	0	0
0	1	1	0	1
1	0	1	0	1
1	1	0	0	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: $\neg A = A \downarrow A$; $A = A \uparrow A$
2. Konjunktion: $A \wedge B = (A \downarrow B) \downarrow (A \downarrow B) = (A \downarrow A) \downarrow (B \downarrow B)$
3. Disjunktion: $A \vee B = (A \downarrow A) \downarrow (B \downarrow B) = (A \uparrow A) \uparrow (B \uparrow B)$

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) $A \wedge B = B \wedge A$; $A \vee B = B \vee A$
- b) $A \wedge \neg A = A \vee \neg A = 1$
- c) $\neg\neg A = A$ (doppelte Negation)
- d) $A \vee \neg A = 1$
- e) $A \wedge \neg A = 0$
- f) $A \vee A = A$; $A \wedge A = A$

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

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

1.2. Boolesche Algebras - Schaltalgebra

Schaltalgebra der Verknüpfungen:

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

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

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

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.

Beispiel 1.2 Der Boolesche Term:

$$p(x, y, z) := (\neg x) \wedge (\neg y) \vee (\neg x) \wedge (zy) \vee (xy)$$

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

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

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

$$q(x, y) = (x \vee y) \wedge (x \vee \neg y)$$

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

R Bogdan



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