Kompressionsalgorithmen: Deflate und bzip2

Seminar „Effiziente Programmierung“

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10.01.2019

Was ist Deflate?

Deflate

- Algorithmus zur verlustlosen Datenkompression
- Hardwareunabhängig, patentfrei
- Ursprünglich für das ZIP-Format entwickelt
- Es gibt einige Implementation des Deflate-Algorithmus:
  - ZIP
  - GZIP
  - Zopfli

Deflate-Algorithmus

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1. Datei wird in Blocks aufgeteilt (häufig 32 KB)

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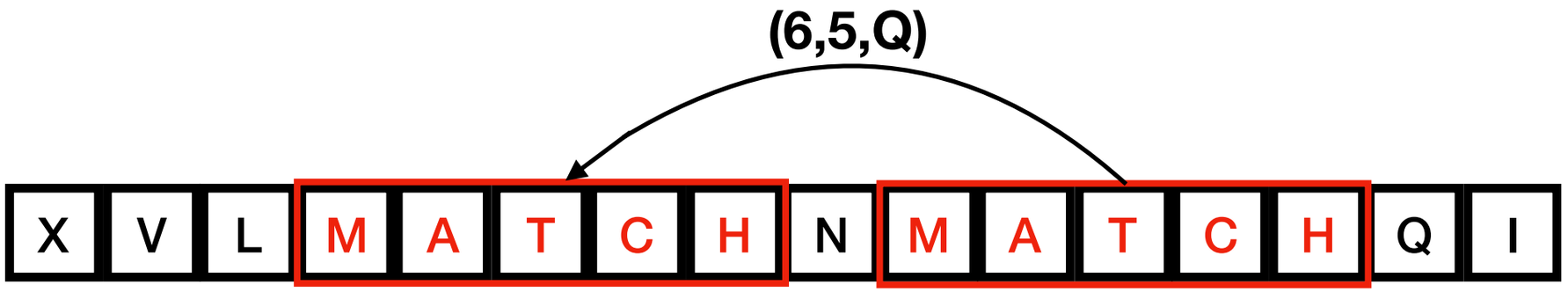
Deflate-Algorithmus

1. Datei wird in Blocks aufgeteilt (häufig 32 KB)
2. LZ77-Algorithmus wird angewandt, um doppelte Zeichenketten zu eliminieren
3. Huffman-Codierung zur Bitreduktion

LZ77

- Wenn Wörter mehrfach vorkommen, speichert man sie nicht erneut, sondern nur eine Referenz auf das erste vorgekommene Wort

- Deduplikation



Huffman-Kodierung

- Wort: ABCD

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- UTF-8:
  - 01000001 01000010 01000011 01000100
  - Mindestens 8 Bit pro Zeichen

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  - 01000001 01000010 01000011 01000100
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Huffman-Kodierung

- Wort: ABCD
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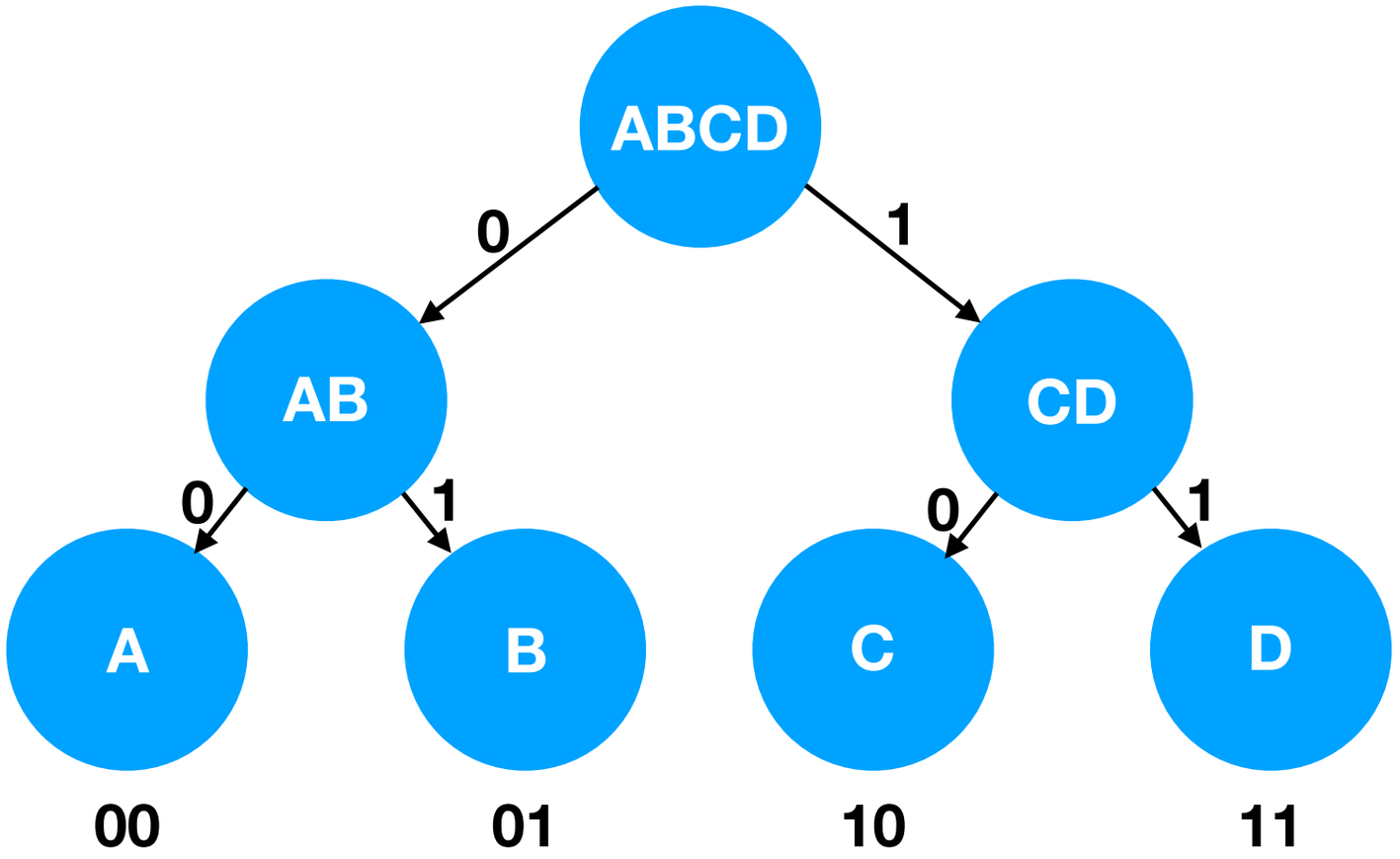
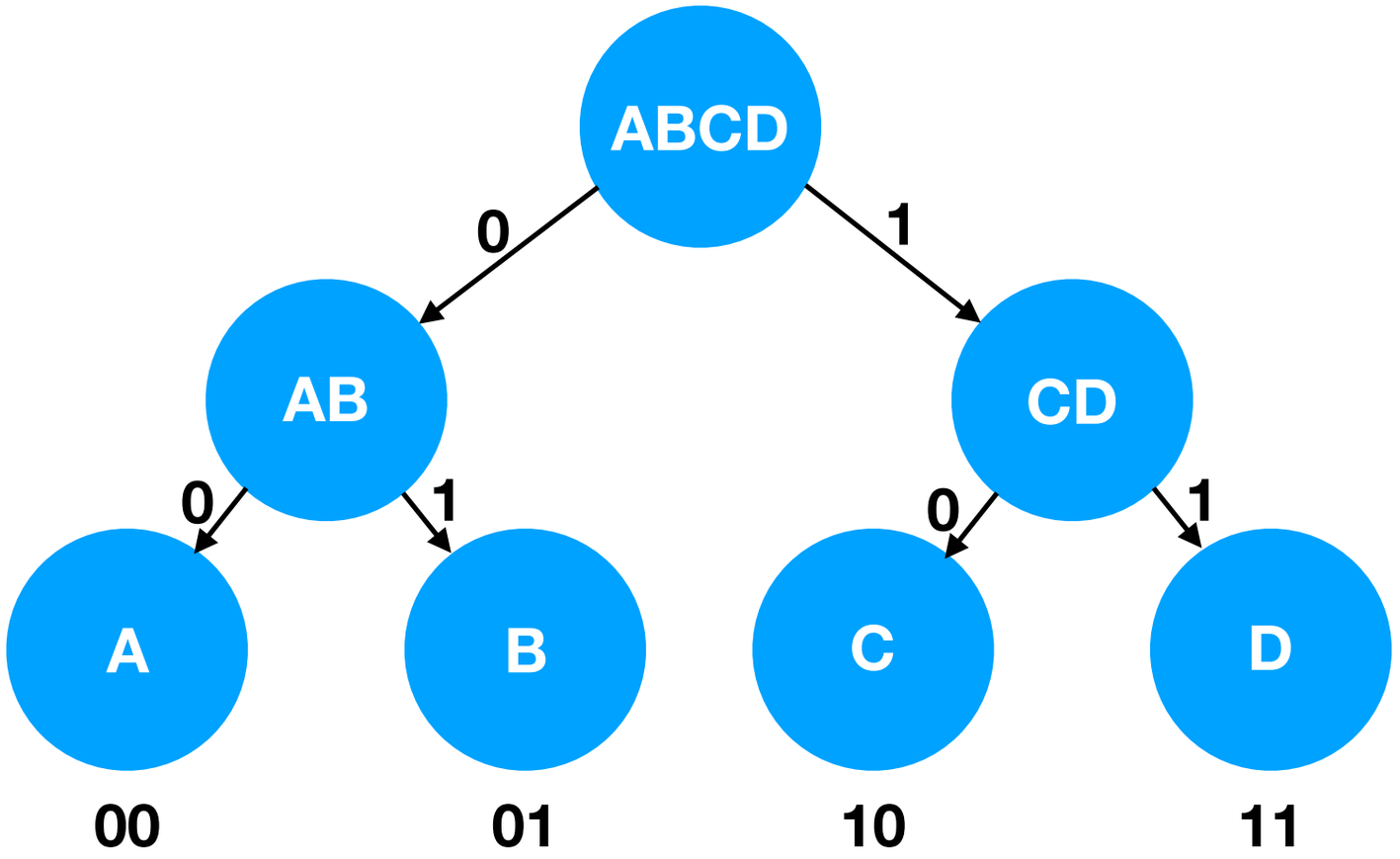
  - 01000001 01000010 01000011 01000100
    - Mindestens 8 Bit pro Zeichen **Überflüssig!**
- Besser:
  - 00 01 10 11
  - 2 Bit pro Zeichen

Huffman-Kodierung



- ABCD = 00 01 10 11
- 2 Bit pro Zeichen

Huffman-Kodierung



- AAAAAABBCD = 00 00 00 00 00 00 01 01 10 11
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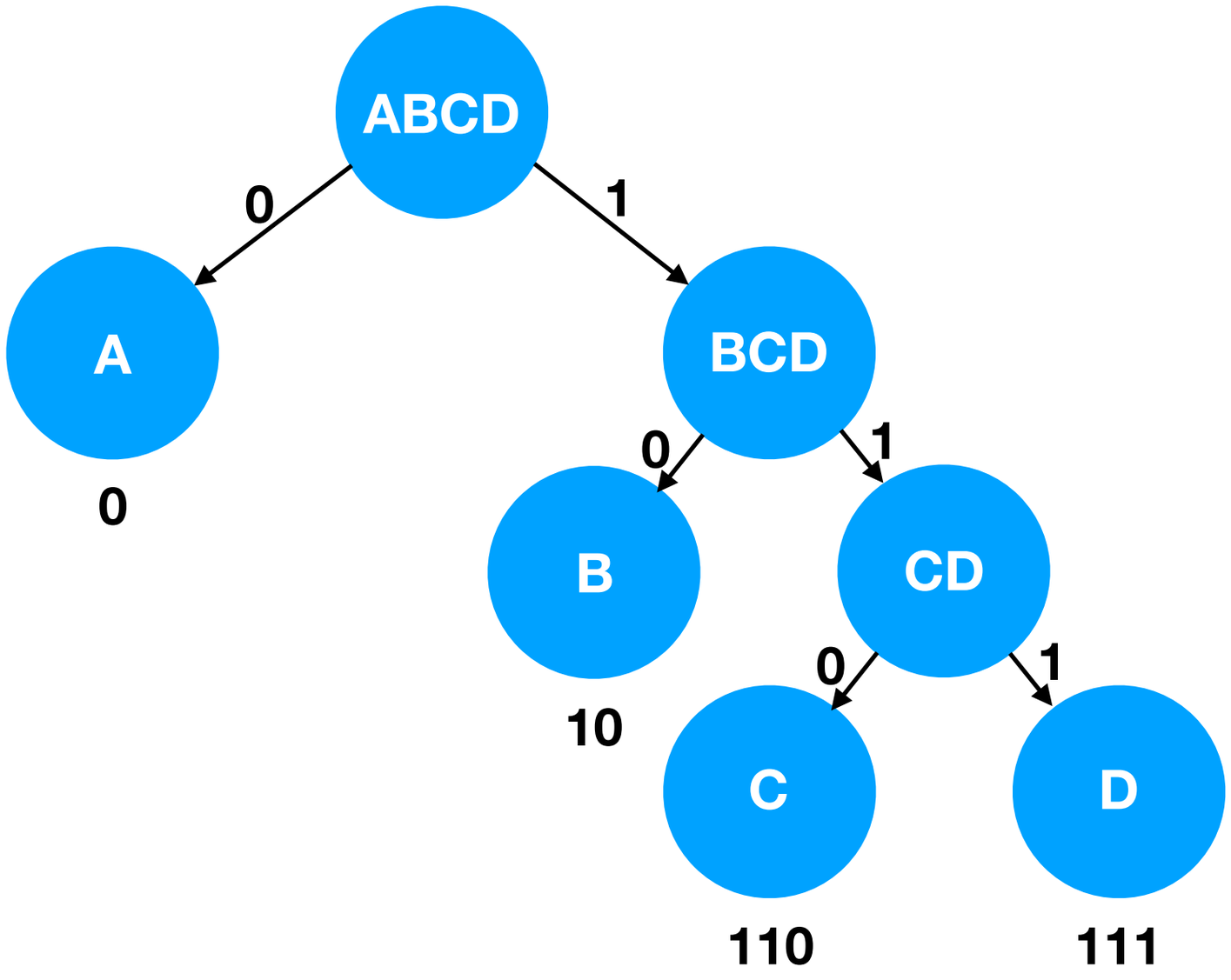
Huffman-Kodierung



- AAAAAABBCD = 0 0 0 0 0 0 10 10 110 111
- 1,6 Bit pro Zeichen

Huffman-Algorithmus

1. Erstelle einen Wald mit Bäumen für jedes Zeichen. Jeder Baum enthält nur einen Knoten.

Wort: AAAAAABBCD

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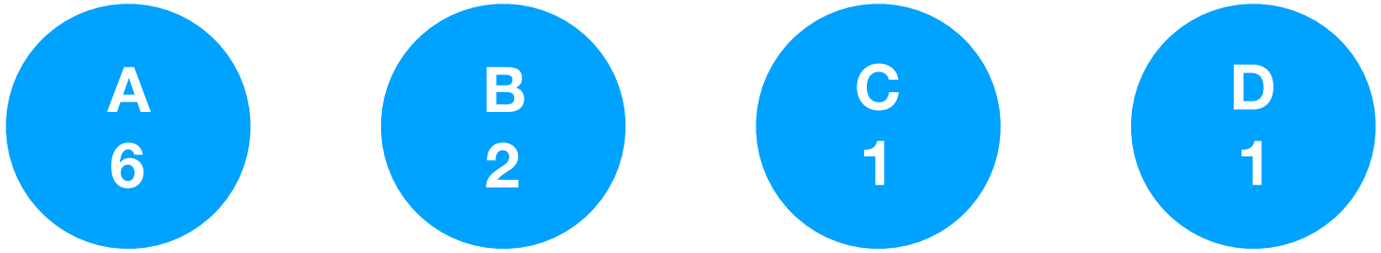

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Huffman-Algorithmus

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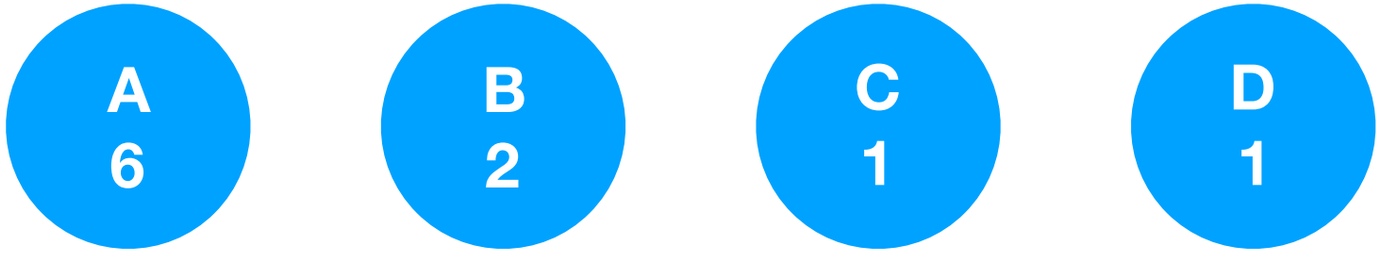

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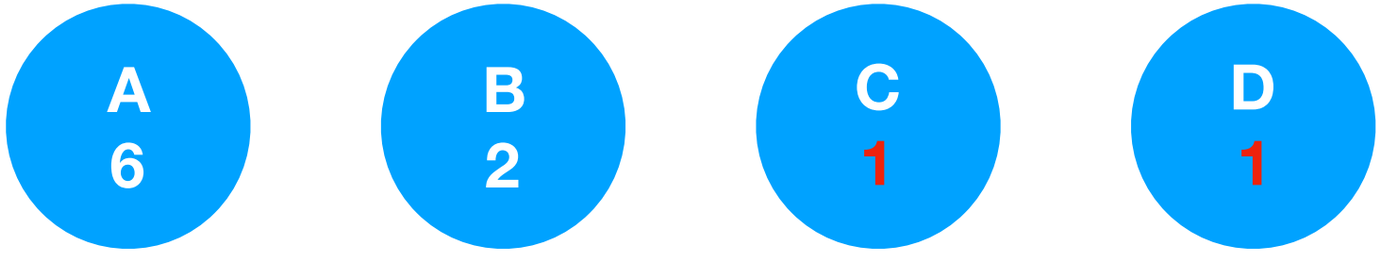

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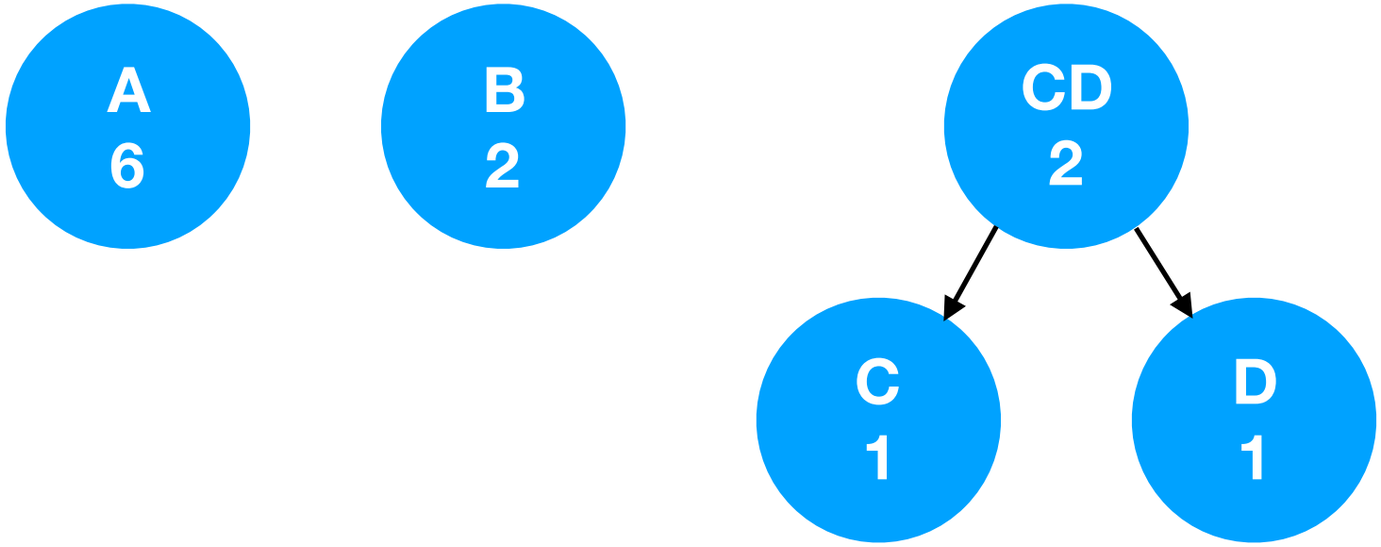

Wort: AAAAAABBCD

Huffman-Algorithmus

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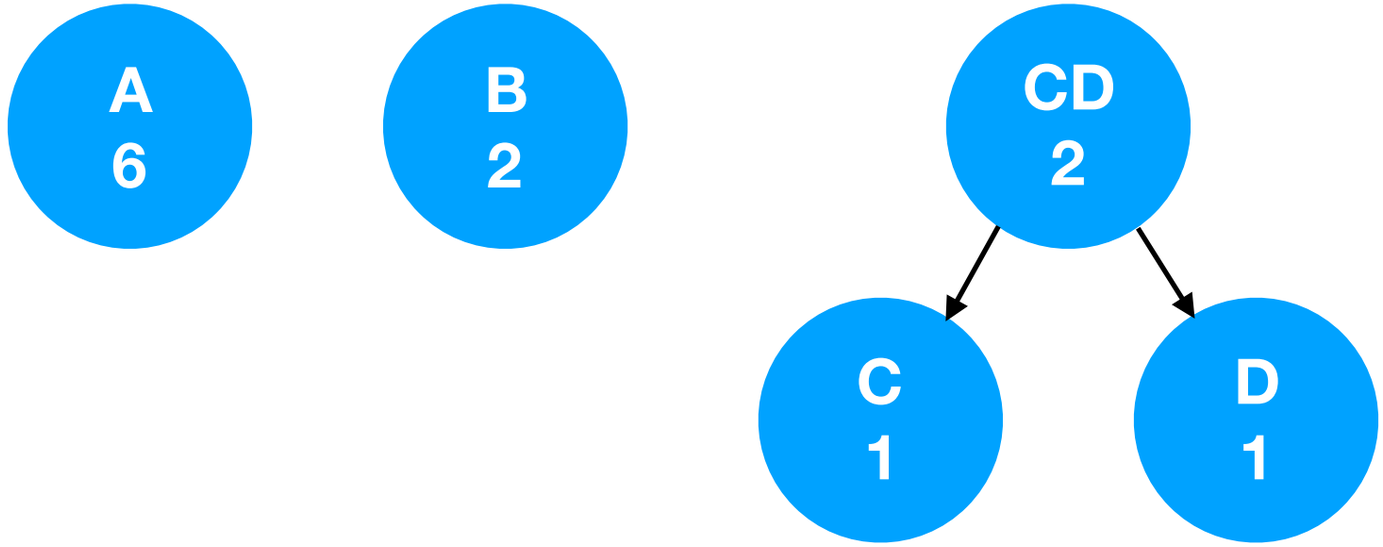
3. Wiederholen, bis nur noch ein Baum übrig ist.



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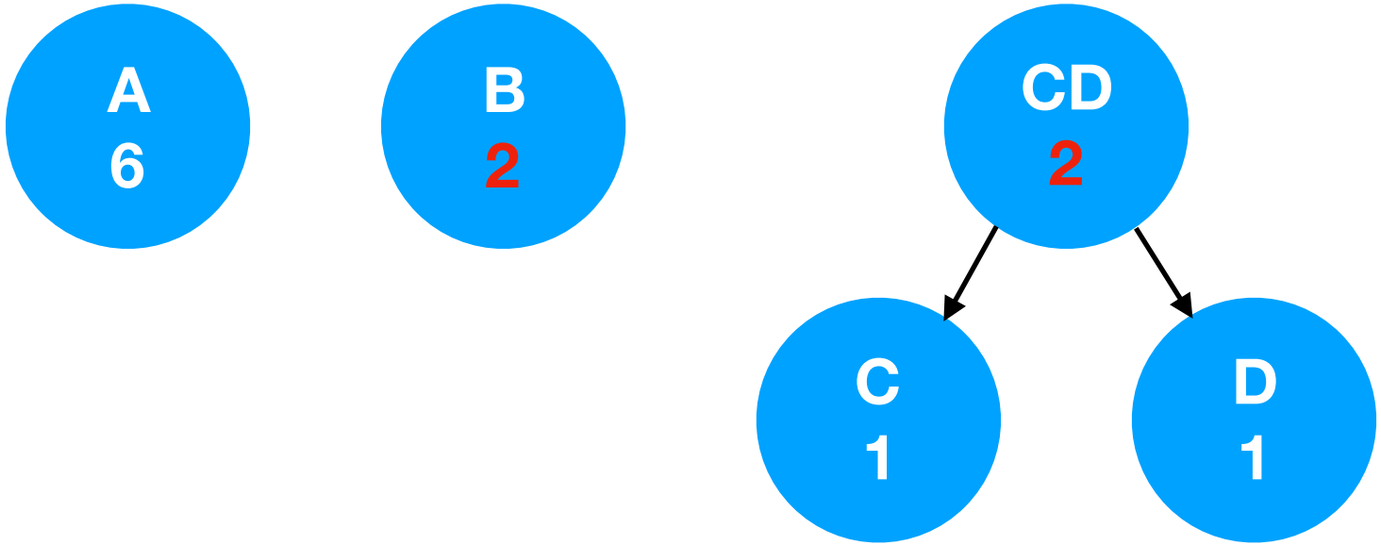

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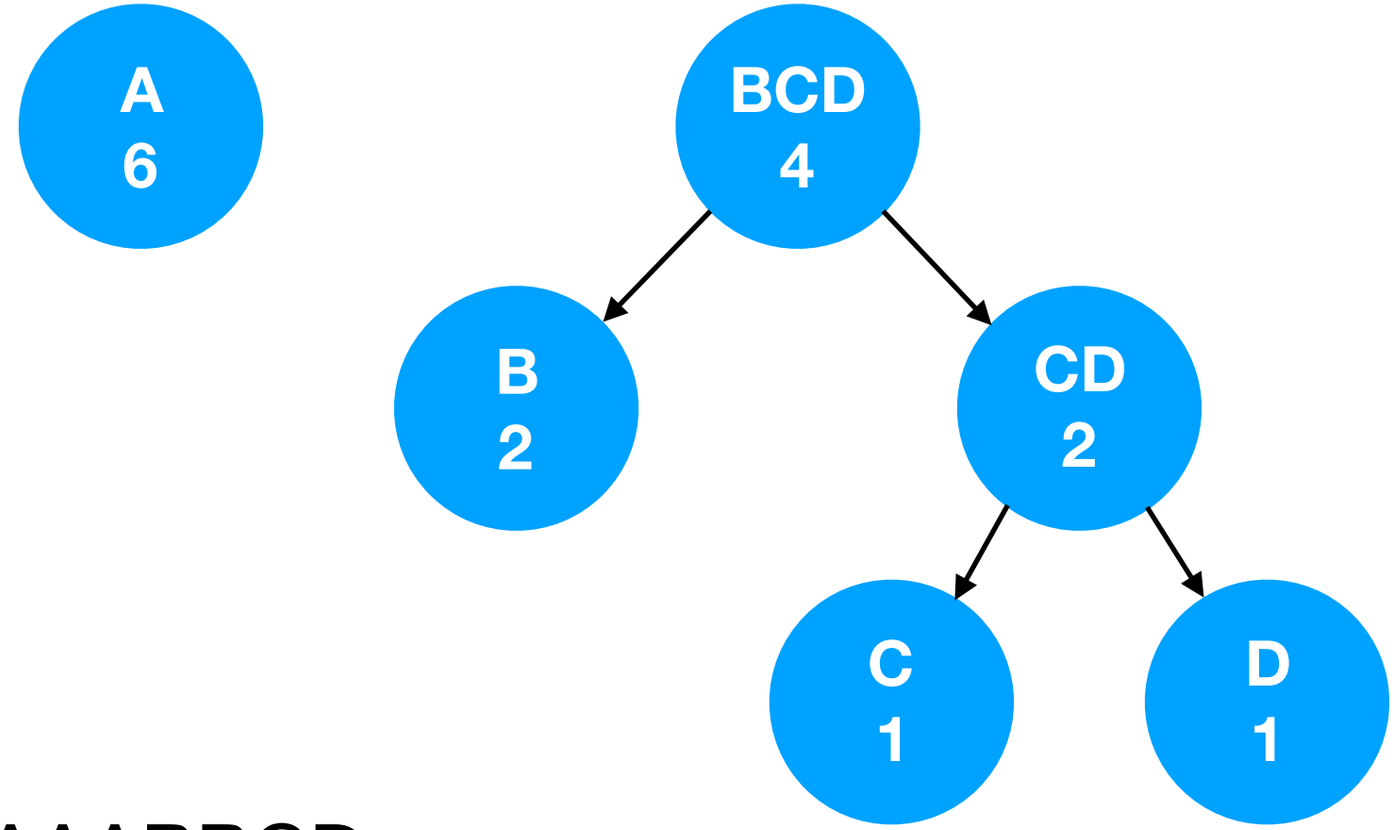

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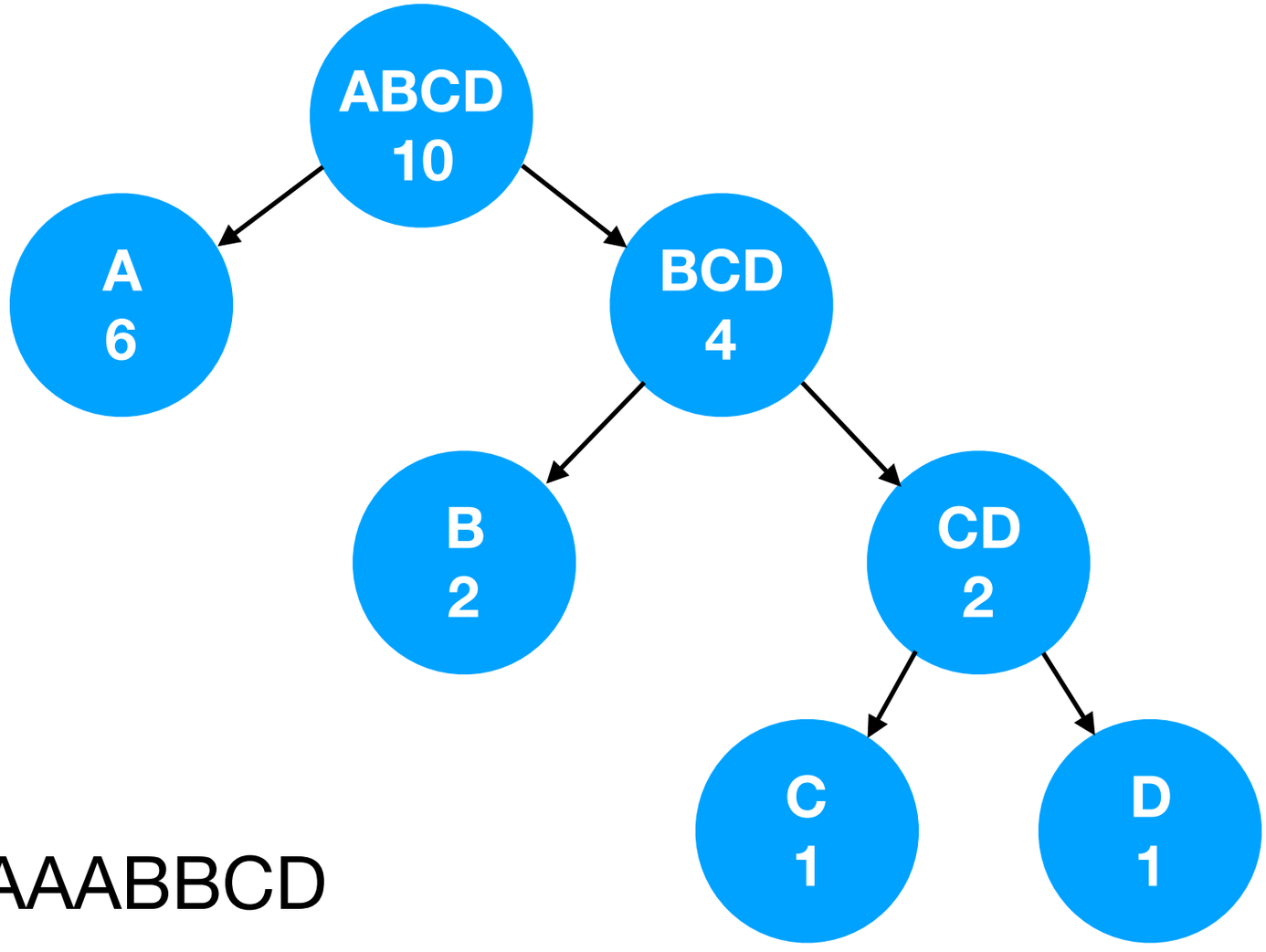

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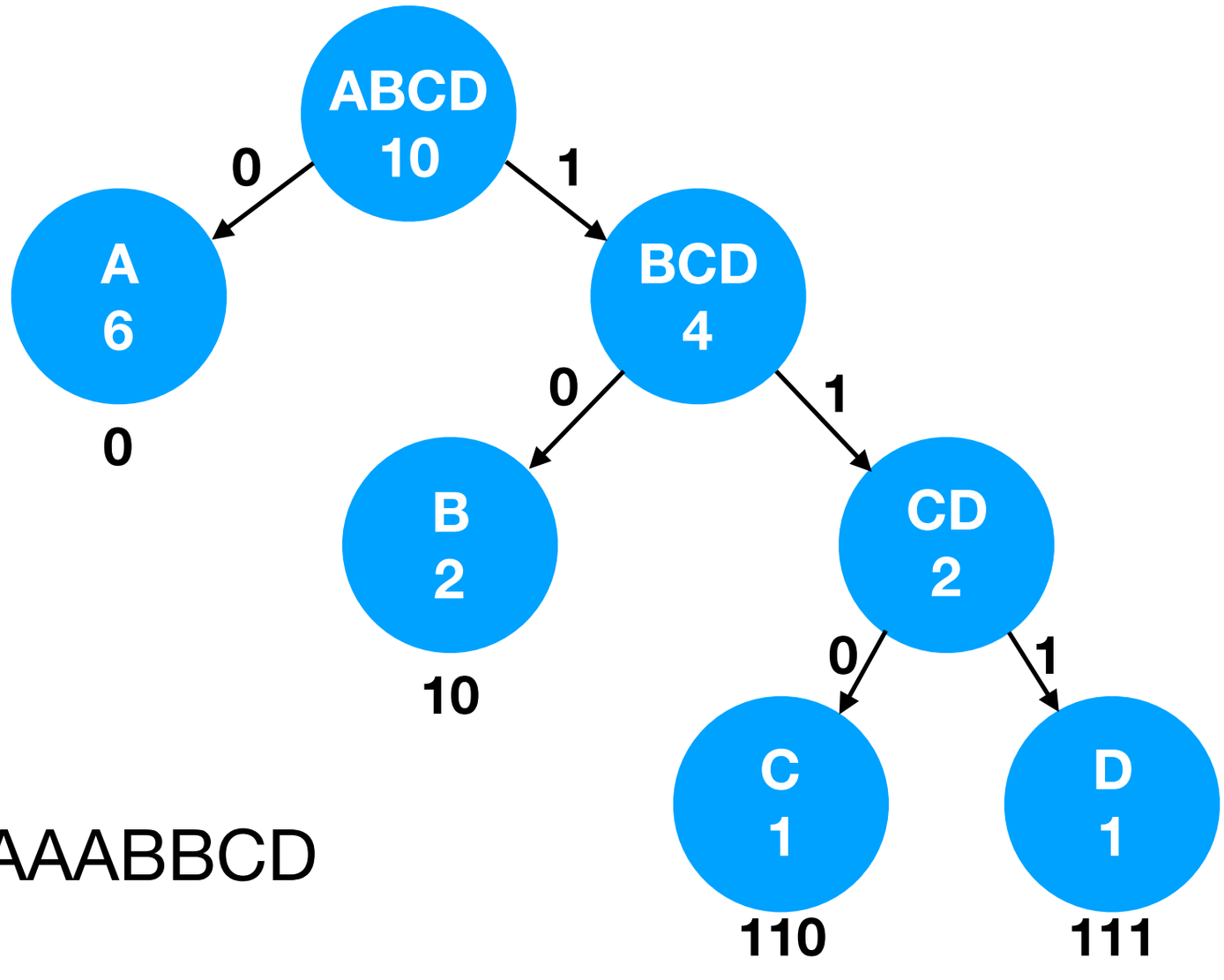


Wort: AAAAAABBCD

Kompressionsalgorithmen

ZIP

- Dateiformat
- 1989 entwickelt
- Erlaubt die Benutzung von mehreren Kompressionsalgorithmen
- Davon ist Deflate der Gebräuchlichste

GZIP

- Software, die Deflate-Dateien erzeugt
- 1992 entwickelt
- Nutzt ähnliche Implementation des Deflate-Algorithmus wie ZIP

Zopfli

- Implementation des Deflate-Algorithmus
- 2012 vom schweizerischem Google-Team entwickelt
- Sehr hohe Kompressionsrate
- Kompression 80-mal langsamer als GZip
- Dekompression bleibt jedoch schnell
- Geeignet für Dateien, die einmalig komprimiert werden

Brotli

- Weitere Entwicklung des Google Teams in 2014
- Kodiert nicht ins Deflate-Format, sondern in ein Eigenes
- Nutzt jedoch ebenfalls LZ77 und Huffman
- Zusätzlich nutzt Brotli ein vordefiniertes Wörterbuch mit 13000 häufig auftretenden Strings

Brotli vs. Deflate

Algorithmus	Kompressionsrate	Kompressionsge-schwindigkeit (MB/s)	Dekompressionsge-schwindigkeit (MB/s)
Brotli 1	3.381	**98.3**	334.0
Brotli 9	3.965	17.0	**354.5**
Brotli 11	**4.347**	0.5	289.5
Deflate 1	2.913	93.5	323.0
Deflate 9	3.371	15.5	347.3

Table 5.3: Performance of Brotli and Deflate and bzip2 [AKSV15]

Gipfeli

- Noch eine Entwicklung des Google Teams
- Kodiert nicht ins Deflate-Format, sondern in ein Eigenes
- Nutzt LZ77, aber kein Huffman
- High-Speed-Kompression

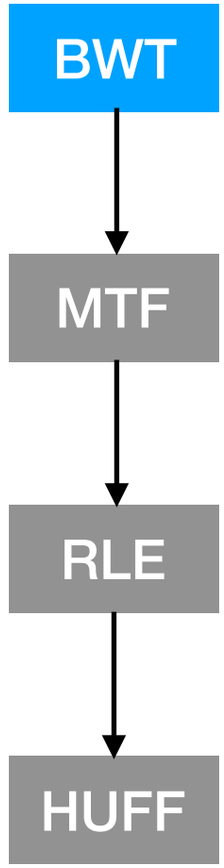
Kompression mit bzip2

bzip2

- Eigener Kompressionsalgorithmus, kein Deflate
- Kombination von verschiedenen Methoden:
  1. Burrows-Wheeler-Transformation
  2. Move-To-Front-Transformation
  3. Run-Length-Encoding
  4. Huffman-Codierung

Burrows-Wheeler-Transformation

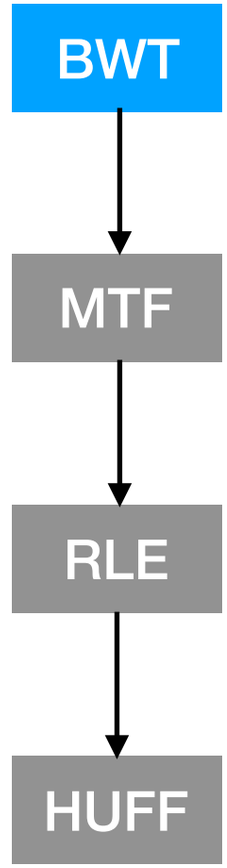
- Eingabe: Wortsequenz, z.B. ANANAS#
- Erzeugt eine Permutation der Eingabe
- Hohe Wahrscheinlichkeit, dass gleiche Zeichen nacheinander auftreten
- Kein Kompressionsalgorithmus!



Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

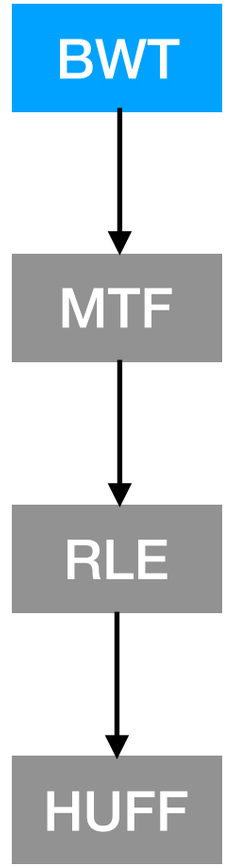
1. Rotieren	2. Sortieren	3. Ergebnis



Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

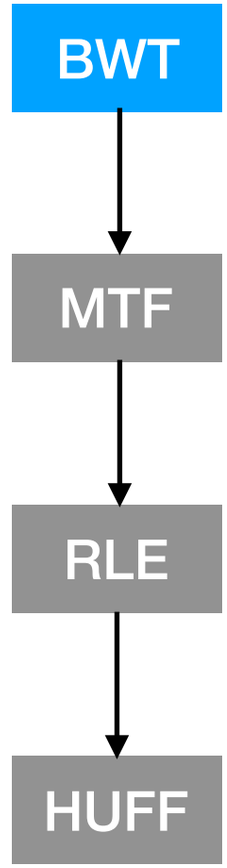
1. Rotieren	2. Sortieren	3. Ergebnis
ANANAS#		
NANAS#A		
ANAS#AN		
NAS#ANA		
AS#ANAN		
S#ANANA		
#ANANAS		



Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

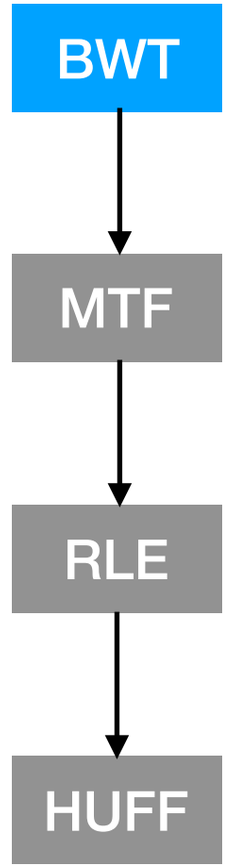
1. Rotieren	2. Sortieren	3. Ergebnis
ANANAS#	#ANANAS	
NANAS#A	ANANAS#	
ANAS#AN	ANAS#AN	
NAS#ANA	AS#ANAN	
AS#ANAN	NANAS#A	
S#ANANA	NAS#ANA	
#ANANAS	S#ANANA	



Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

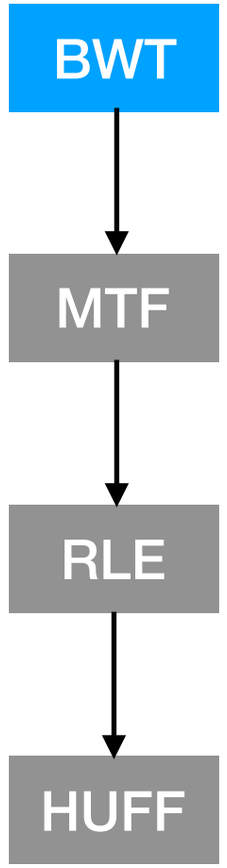
1. Rotieren	2. Sortieren	3. Ergebnis
ANANAS#	#ANANAS	
NANAS#A	ANANAS#	
ANAS#AN	ANAS#AN	
NAS#ANA	AS#ANAN	
AS#ANAN	NANAS#A	
S#ANANA	NAS#ANA	
#ANANAS	S#ANANA	



Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

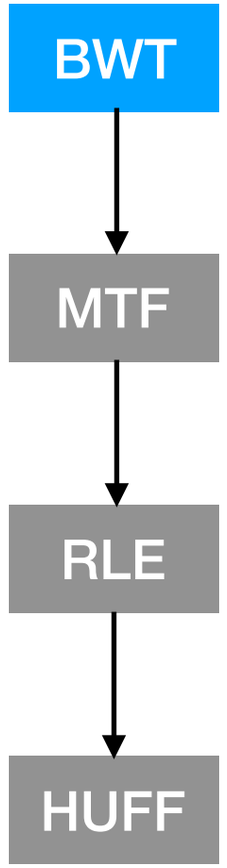
1. Rotieren	2. Sortieren	3. Ergebnis
ANANAS#	#ANANAS	S
NANAS#A	ANANAS#	#
ANAS#AN	ANAS#AN	N
NAS#ANA	AS#ANAN	N
AS#ANAN	NANAS#A	A
S#ANANA	NAS#ANA	A
#ANANAS	S#ANANA	A



Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

1. Rotieren	2. Sortieren	3. Ergebnis
ANANAS#	#ANANAS	S
NANAS#A	ANANAS#	#
ANAS#AN	ANAS#AN	N
NAS#ANA	AS#ANAN	N
AS#ANAN	NANAS#A	A
S#ANANA	NAS#ANA	A
#ANANAS	S#ANANA	A

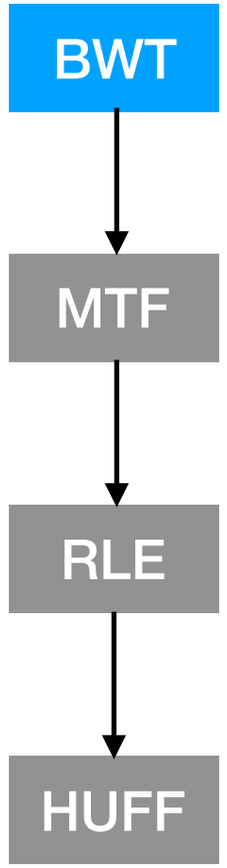


- Ausgabe: S#NNAAA

Burrows-Wheeler-Transformation

- Eingabe: ANANAS#

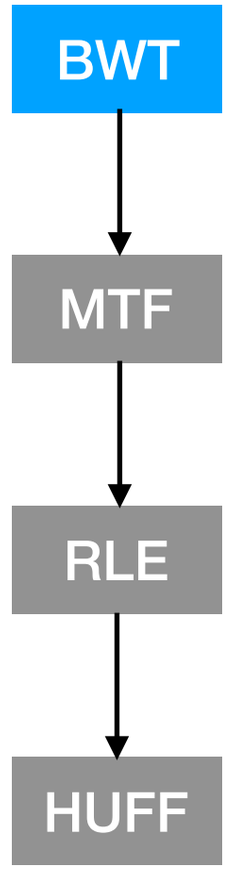
1. Rotieren	2. Sortieren	3. Ergebnis
ANANAS#	#ANANAS	S
NANAS#A	ANANAS#	#
ANAS#AN	ANAS#AN	N
NAS#ANA	AS#ANAN	N
AS#ANAN	NANAS#A	A
S#ANANA	NAS#ANA	A
#ANANAS	S#ANANA	A



- Ausgabe: S#NNAAA, 1

Burrows-Wheeler-Transformation

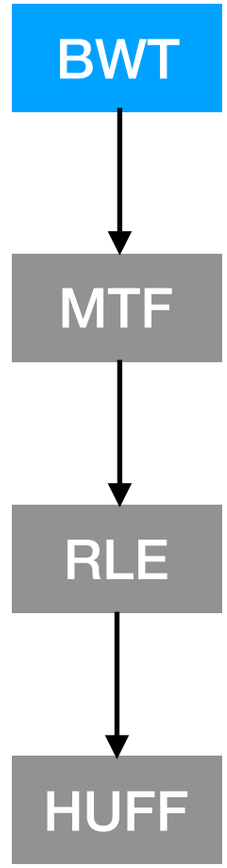
- Bei längeren Wörtern ist der Effekt deutlicher:
- Eingabe: ANANAS#ANANAS#ANANAS#
- Ausgabe: SSS###NNNNNNAAAAAAAAA, 3



BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

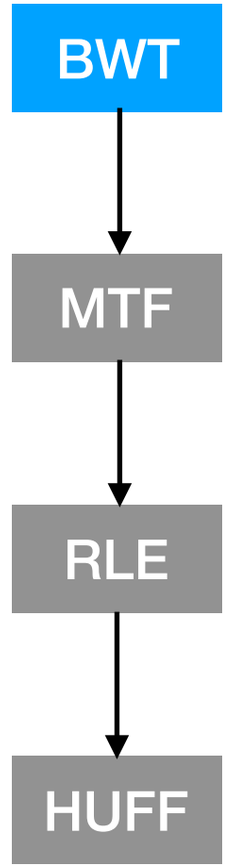
1. Rotieren	2. Sortieren	3. Ergebnis
?	?	?
?	?	?
?	?	?
?	?	?
?	?	?
?	?	?
?	?	?



BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

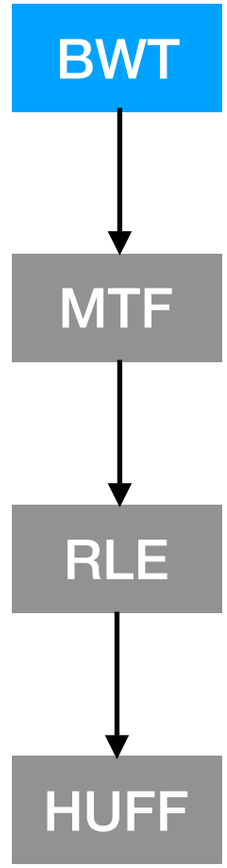
1. Rotieren	2. Sortieren	3. Ergebnis
?	?	S
?	?	#
?	?	N
?	?	N
?	?	A
?	?	A
?	?	A



BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

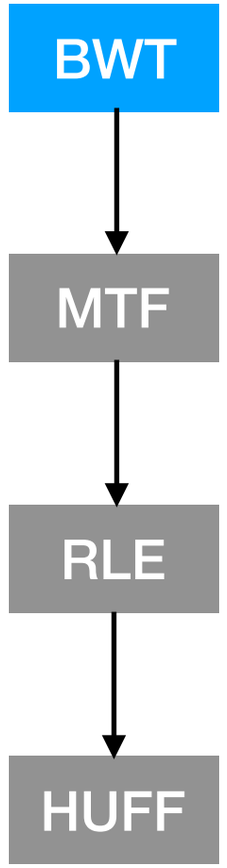
1. Rotieren	2. Sortieren	3. Ergebnis
?	??????S	S
?	??????#	#
?	??????N	N
?	??????N	N
?	??????A	A
?	??????A	A
?	??????A	A



BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

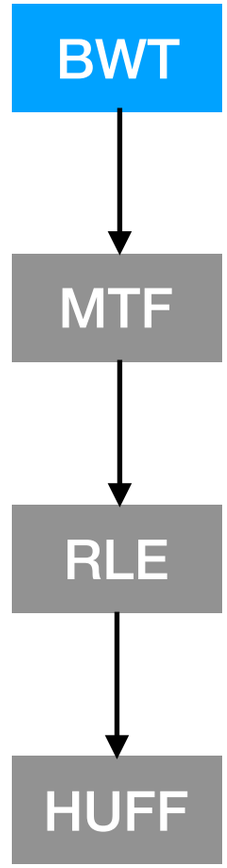
1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A



BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

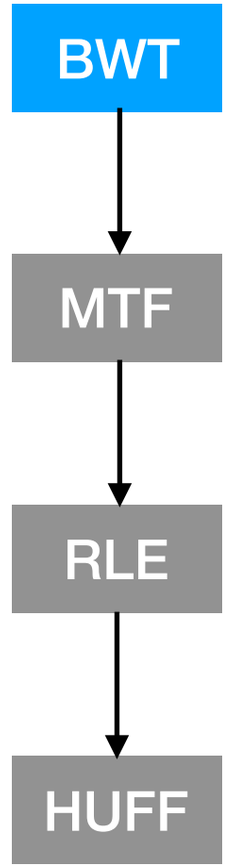
1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A



BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A

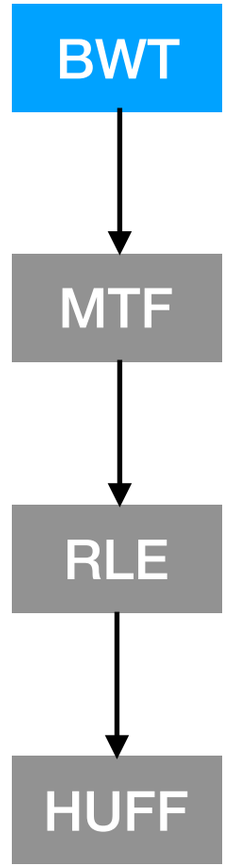


- Ausgabe: A

BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A

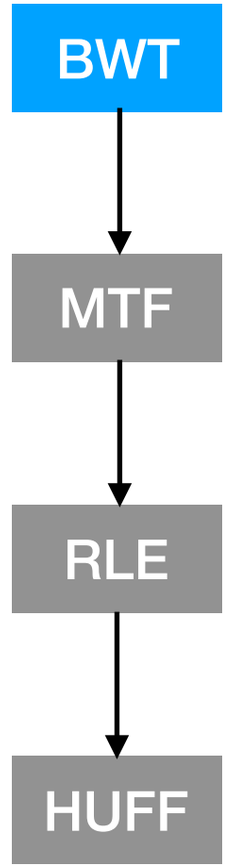


- Ausgabe: A

BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A

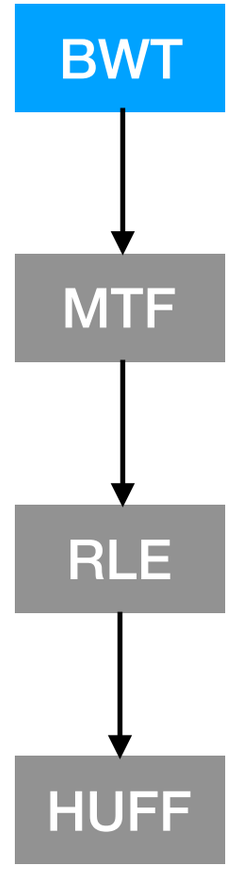


- Ausgabe: AN

BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A

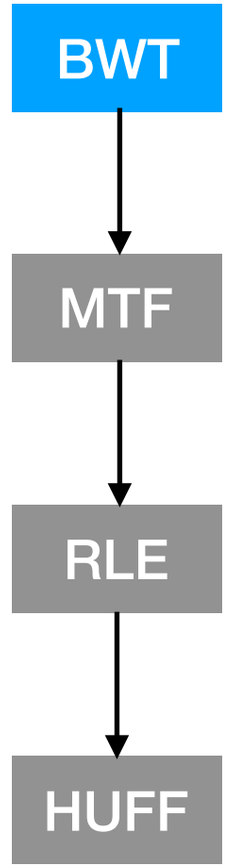


- Ausgabe: AN

BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A

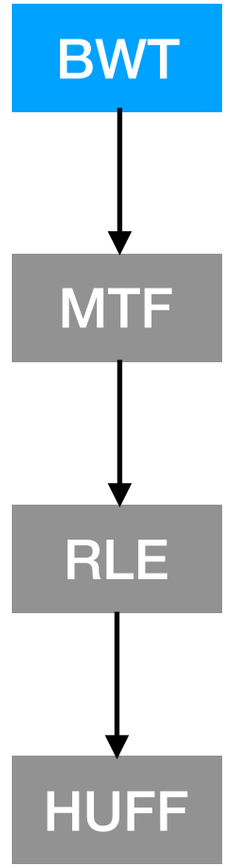


- Ausgabe: ANA

BWT-Rücktransformation

- Eingabe: S#NNAAA, 1

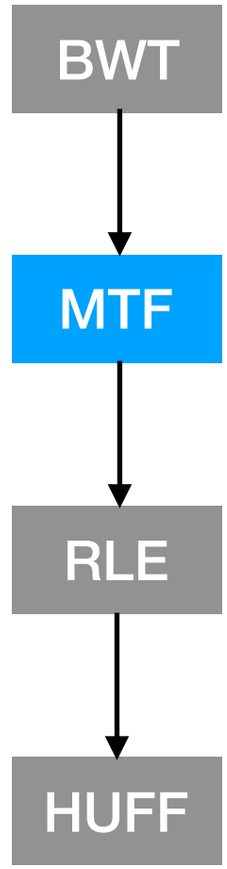
1. Rotieren	2. Sortieren	3. Ergebnis
?	#?????S	S
?	A?????#	#
?	A?????N	N
?	A?????N	N
?	N?????A	A
?	N?????A	A
?	S?????A	A



- Ausgabe: ANANAS#

Move-To-Front-Transformation

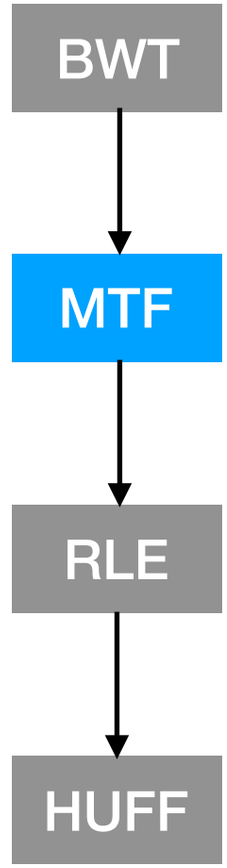
- Eingabe:
  - Wortsequenz
  - Alphabet dieser Wortsequenz
- Erzeugt eine Permutation der Eingabe
- Nacheinander auftretende Zeichen in der Eingabe resultieren in vielen 0en in der Ausgabe
- Auch hierbei handelt es sich noch nicht um eine Kompression!



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

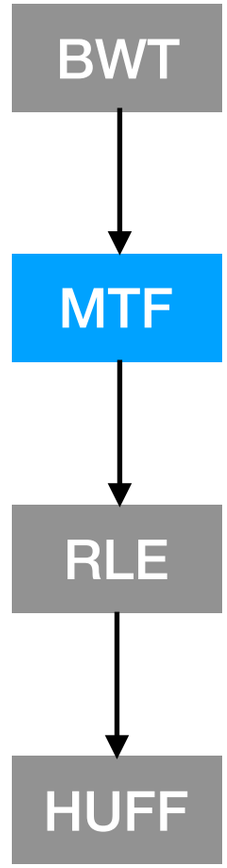
Input	Alphabet	Output	Alphabet’



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

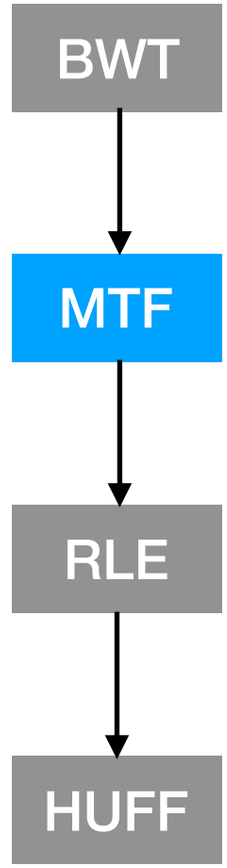
Input	Alphabet	Output	Alphabet’
S			
#			
N			
N			
A			
A			
A			



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

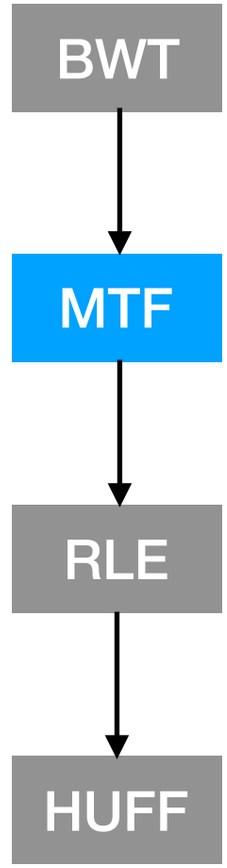
Input	Alphabet	Output	Alphabet’
S	#ANS		
#			
N			
N			
A			
A			
A			



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

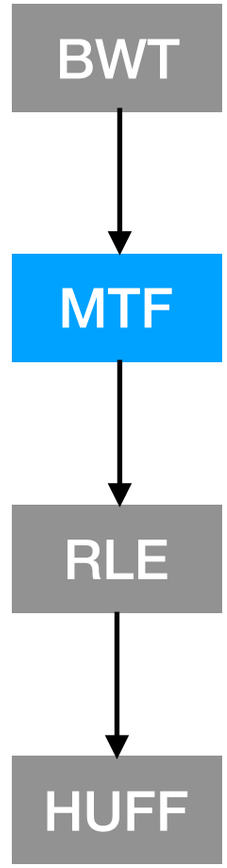
Input	Alphabet	Output	Alphabet’
S	#ANS	3	
#			
N			
N			
A			
A			
A			



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

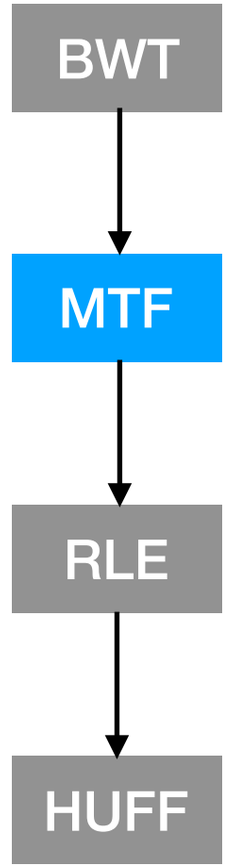
Input	Alphabet	Output	Alphabet’
S	#ANS	3	S#AN
#			
N			
N			
A			
A			
A			



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

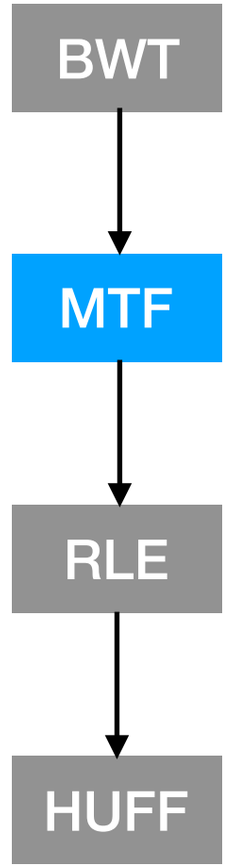
Input	Alphabet	Output	Alphabet’
S	#ANS	3	S#AN
#	S#AN		
N			
N			
A			
A			
A			



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

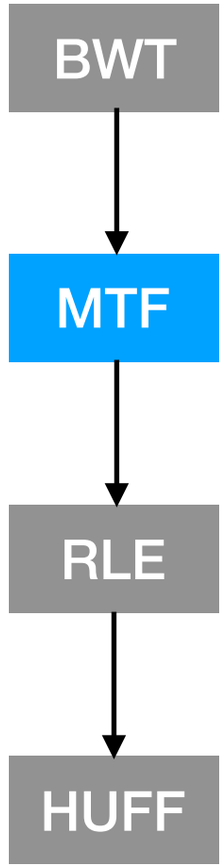
Input	Alphabet	Output	Alphabet’
S	#ANS	3	S#AN
#	S#AN	1	#SAN
N	#SAN		
N			
A			
A			
A			



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

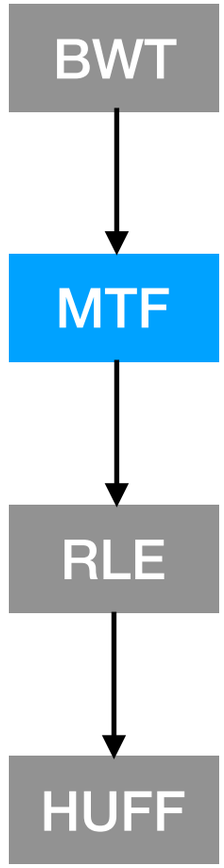
Input	Alphabet	Output	Alphabet’
S	#ANS	3	S#AN
#	S#AN	1	#SAN
N	#SAN	3	N#SA
N	N#SA	0	N#SA
A	N#SA	3	AN#S
A	AN#S	0	AN#S
A	AN#S	0	AN#S



Move-To-Front-Transformation

- Eingabe: S#NNAAA, #ANS

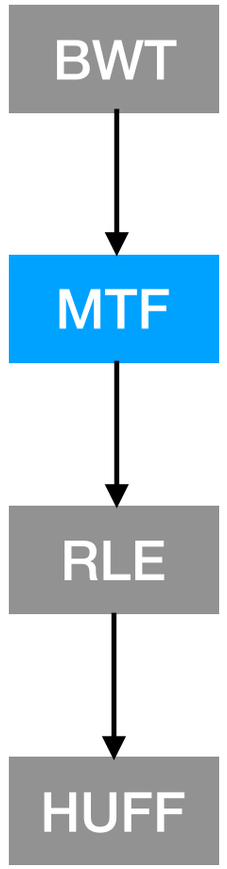
Input	Alphabet	Output	Alphabet’
S	#ANS	3	S#AN
#	S#AN	1	#SAN
N	#SAN	3	N#SA
N	N#SA	0	N#SA
A	N#SA	3	AN#S
A	AN#S	0	AN#S
A	AN#S	0	AN#S



- Ausgabe: 3130300, AN#S

Move-To-Front-Transformation

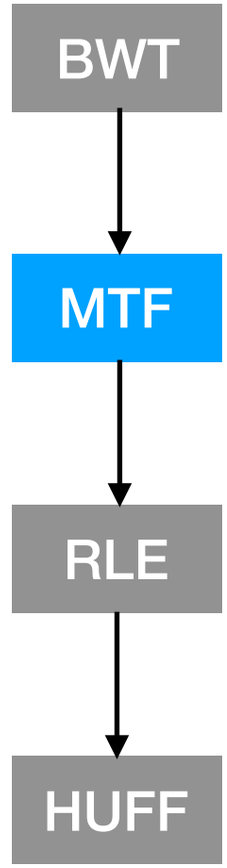
- Auch hier ist bei längeren Wörtern der Effekt deutlicher:
- Eingabe: SSS###NNNNNNAAAAAAAAA
- Ausgabe: 300100300000300000000, AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

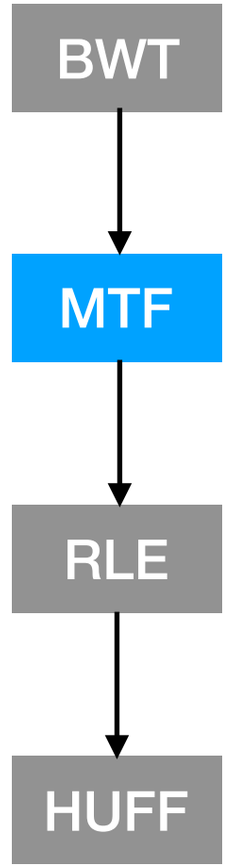
Output	Alphabet	Input	Alphabet’



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

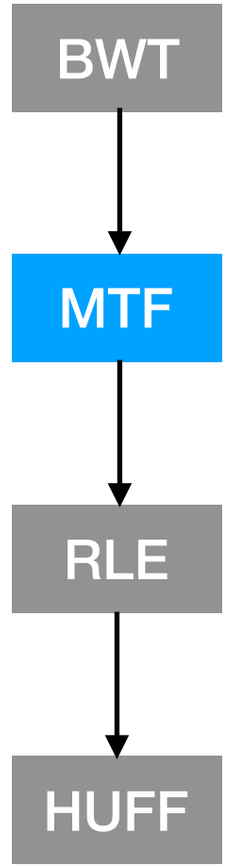
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	
		3	
		0	
		0	



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

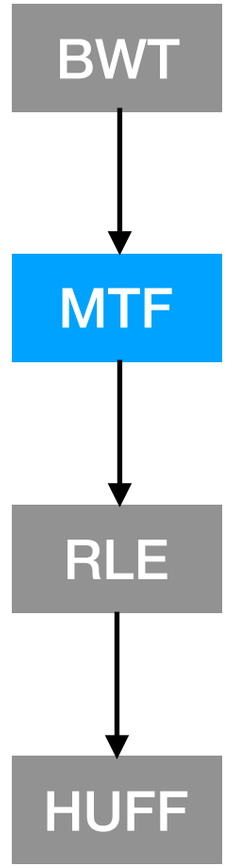
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	
		3	
		0	
		0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

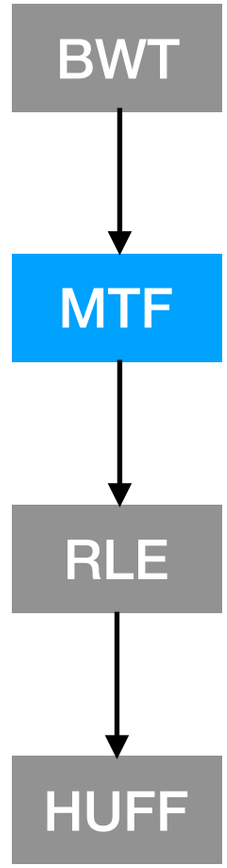
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	
		3	
		0	
A		0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

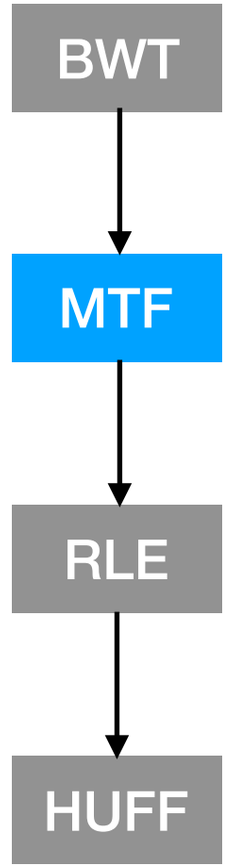
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	
		3	
		0	
A	AN#S	0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

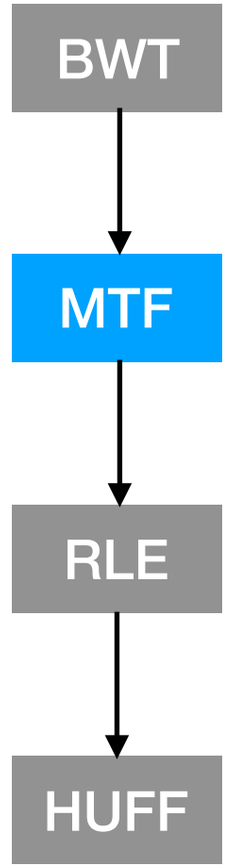
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	
		3	
		0	AN#S
A	AN#S	0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

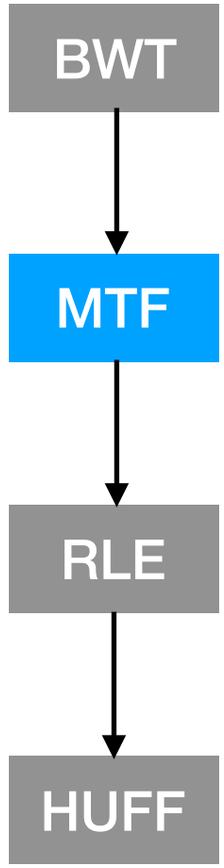
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	
		3	AN#S
A	AN#S	0	AN#S
A	AN#S	0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

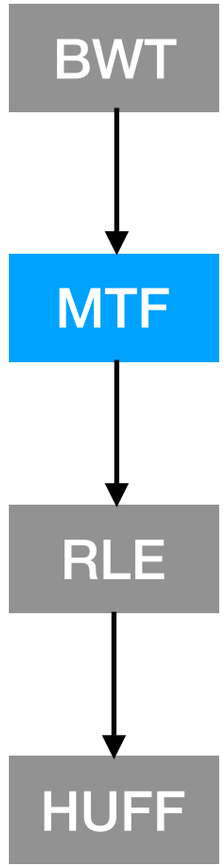
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	
		0	N#SA
A	N#SA	3	AN#S
A	AN#S	0	AN#S
A	AN#S	0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

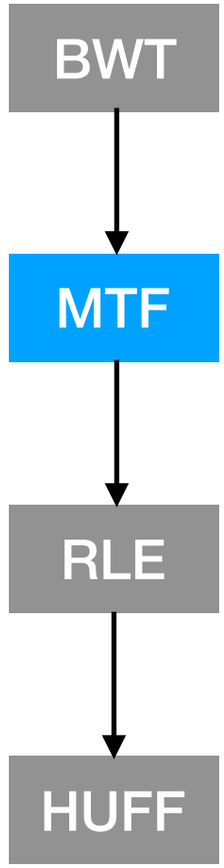
Output	Alphabet	Input	Alphabet’
		3	
		1	
		3	N#SA
N	N#SA	0	N#SA
A	N#SA	3	AN#S
A	AN#S	0	AN#S
A	AN#S	0	AN#S



MTF-Rücktransformation

- Eingabe: 3130300, AN#S

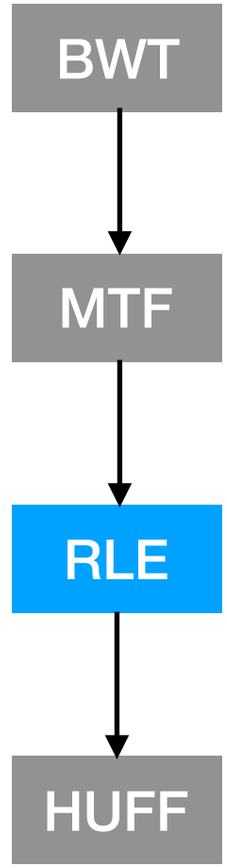
Output	Alphabet	Input	Alphabet’
S	#ANS	3	S#AN
#	S#AN	1	#SAN
N	#SAN	3	N#SA
N	N#SA	0	N#SA
A	N#SA	3	AN#S
A	AN#S	0	AN#S
A	AN#S	0	AN#S



- Ausgabe: S#NNAAA

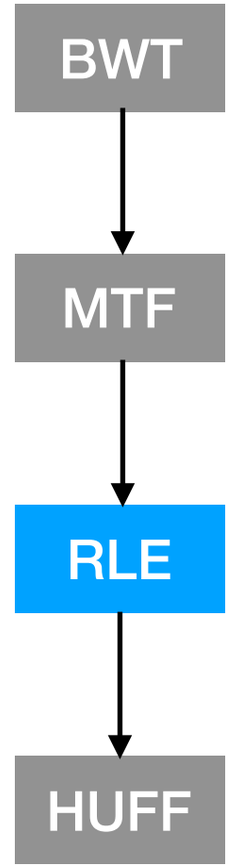
Run-Length-Encoding

- Gleiche aufeinanderfolgende Zeichen werden abgekürzt:
- z.B. AAAAAABBCD -> A6B2C1D1
- Deduplikation



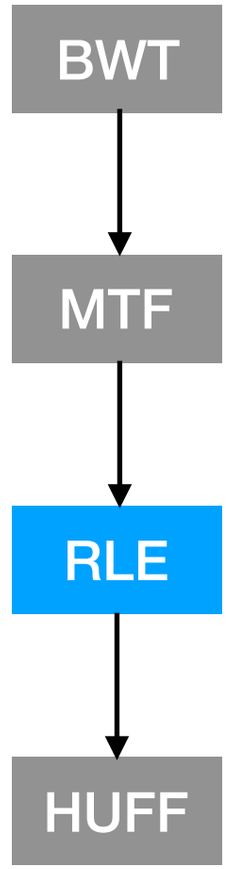
Run-Length-Encoding

- Eingabe: 300100300000300000000



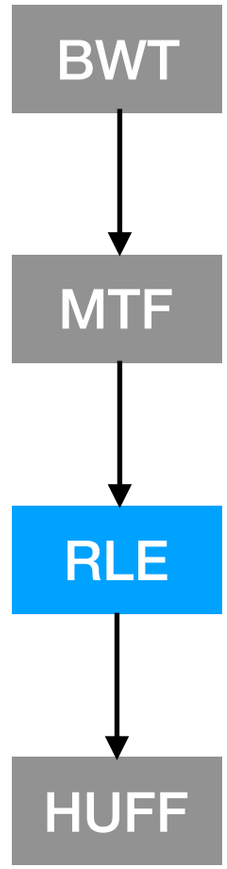
Run-Length-Encoding

- Eingabe: 3 00 1 00 3 00000 3 00000000



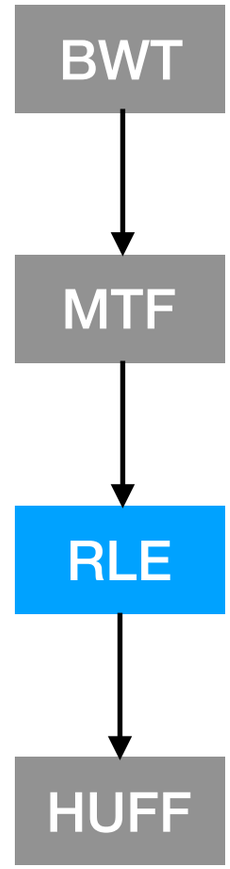
Run-Length-Encoding

- Eingabe: 3 00 1 00 3 00000 3 00000000
- Ausgabe: 31 02 11 02 31 05 31 08



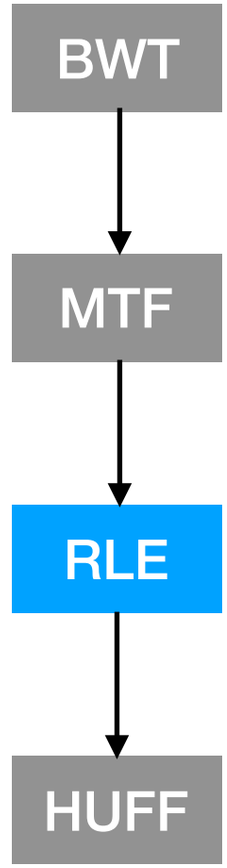
Run-Length-Encoding

- Eingabe: 3 00 1 00 3 00000 3 00000000
- Ausgabe: 3102110231053108



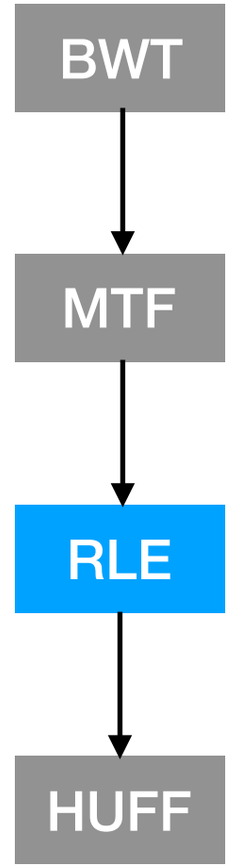
RLE-Dekodierung

- Eingabe: 31021102310531O8



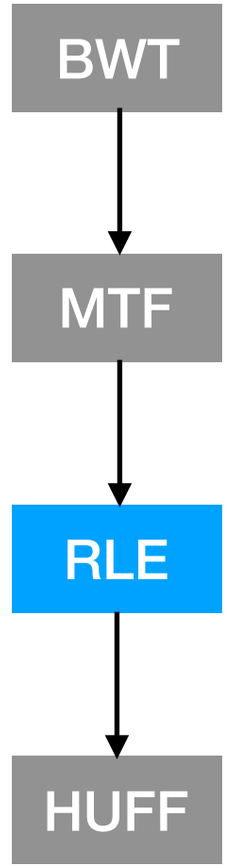
RLE-Dekodierung

- Eingabe: 31 02 11 02 31 05 31 08



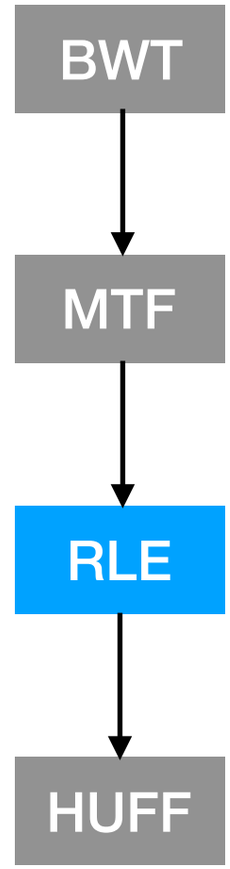
RLE-Dekodierung

- Eingabe: 31 02 11 02 31 05 31 08
- Ausgabe: 3 00 1 00 3 00000 3 00000000



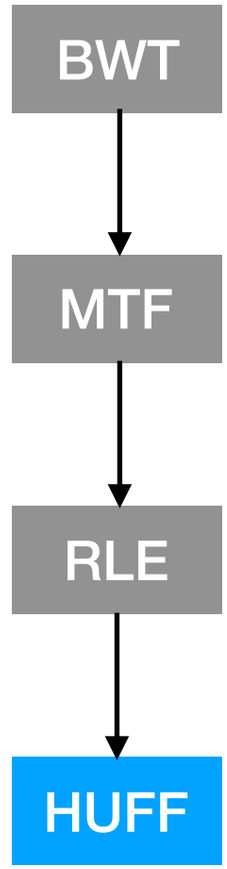
RLE-Dekodierung

- Eingabe: 31 02 11 02 31 05 31 08
- Ausgabe: 300100300000300000000



Huffman-Kodierung

- Eingabe: 31021102310531O8



Huffman-Kodierung

- Eingabe: 31021102310531O8

0 : 4 mal

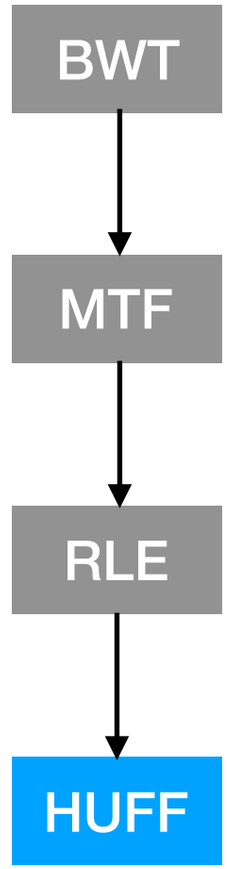
1 : 5 mal

2 : 2 mal

3 : 3 mal

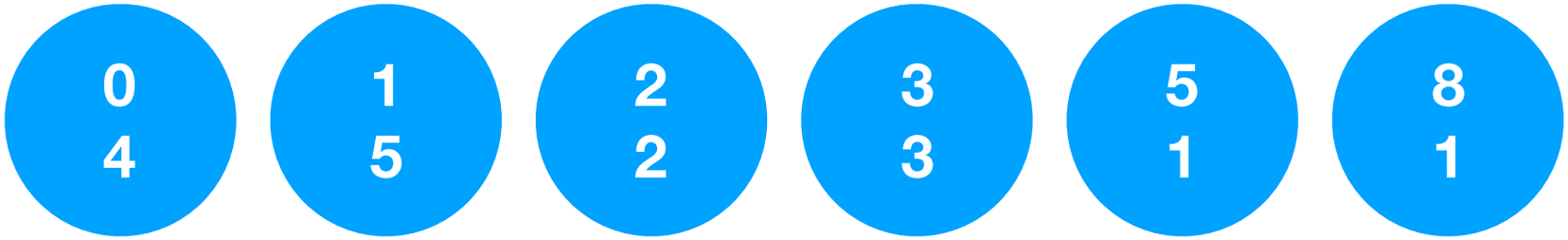
5 : 1 mal

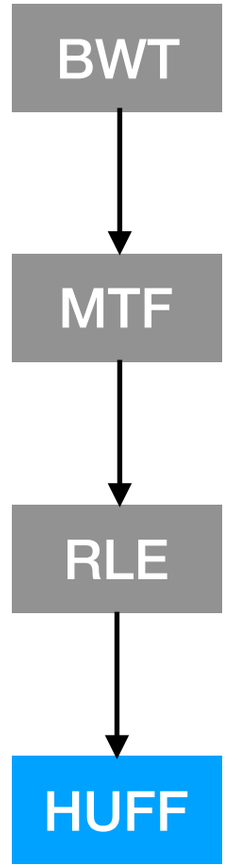
8 : 1 mal



Huffman-Kodierung

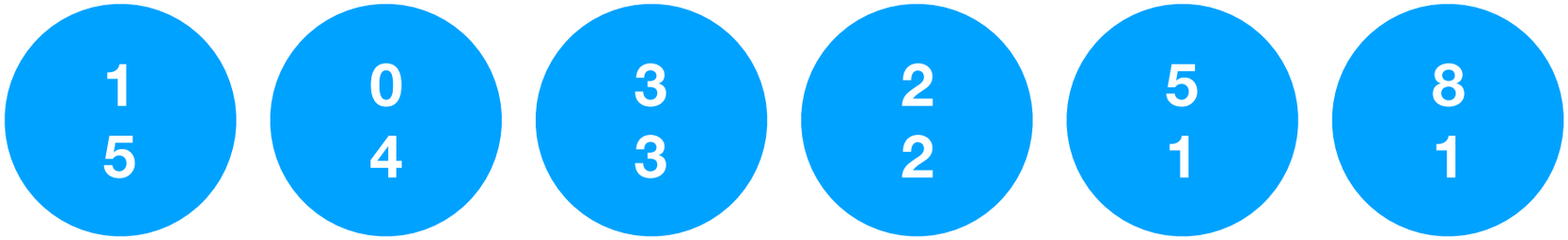
- Eingabe: 31021102310531O8

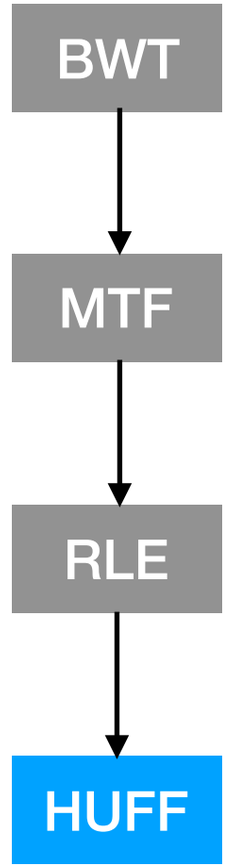




Huffman-Kodierung

- Eingabe: 31021102310531O8





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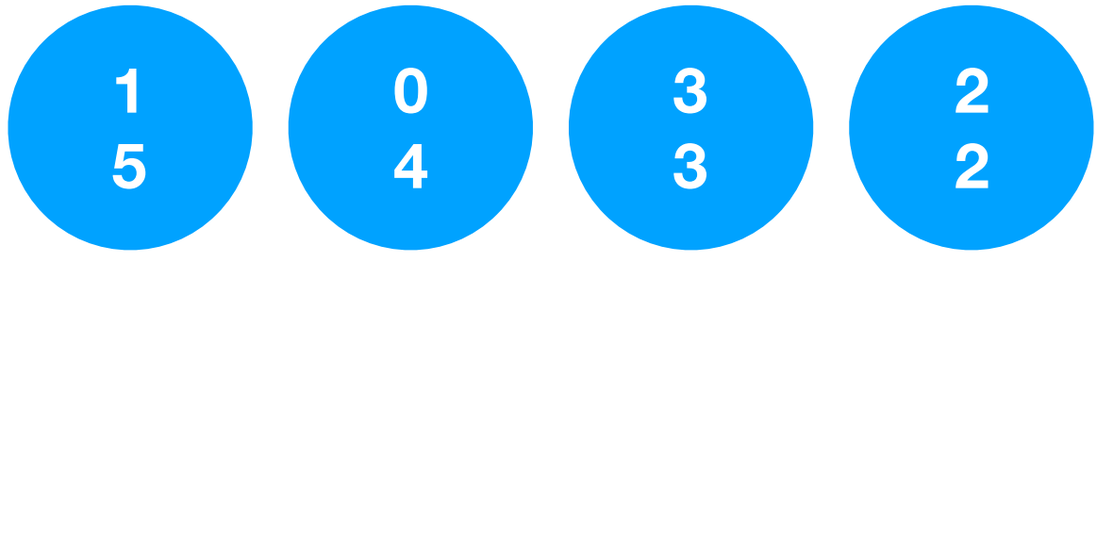

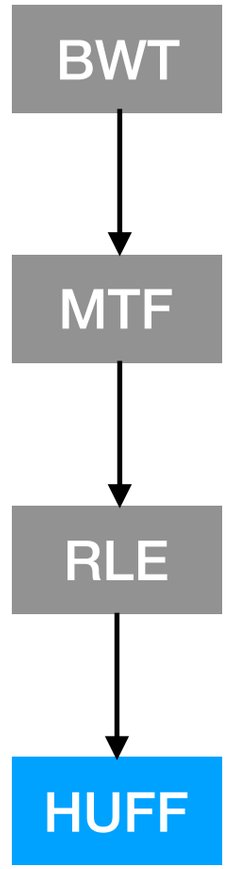

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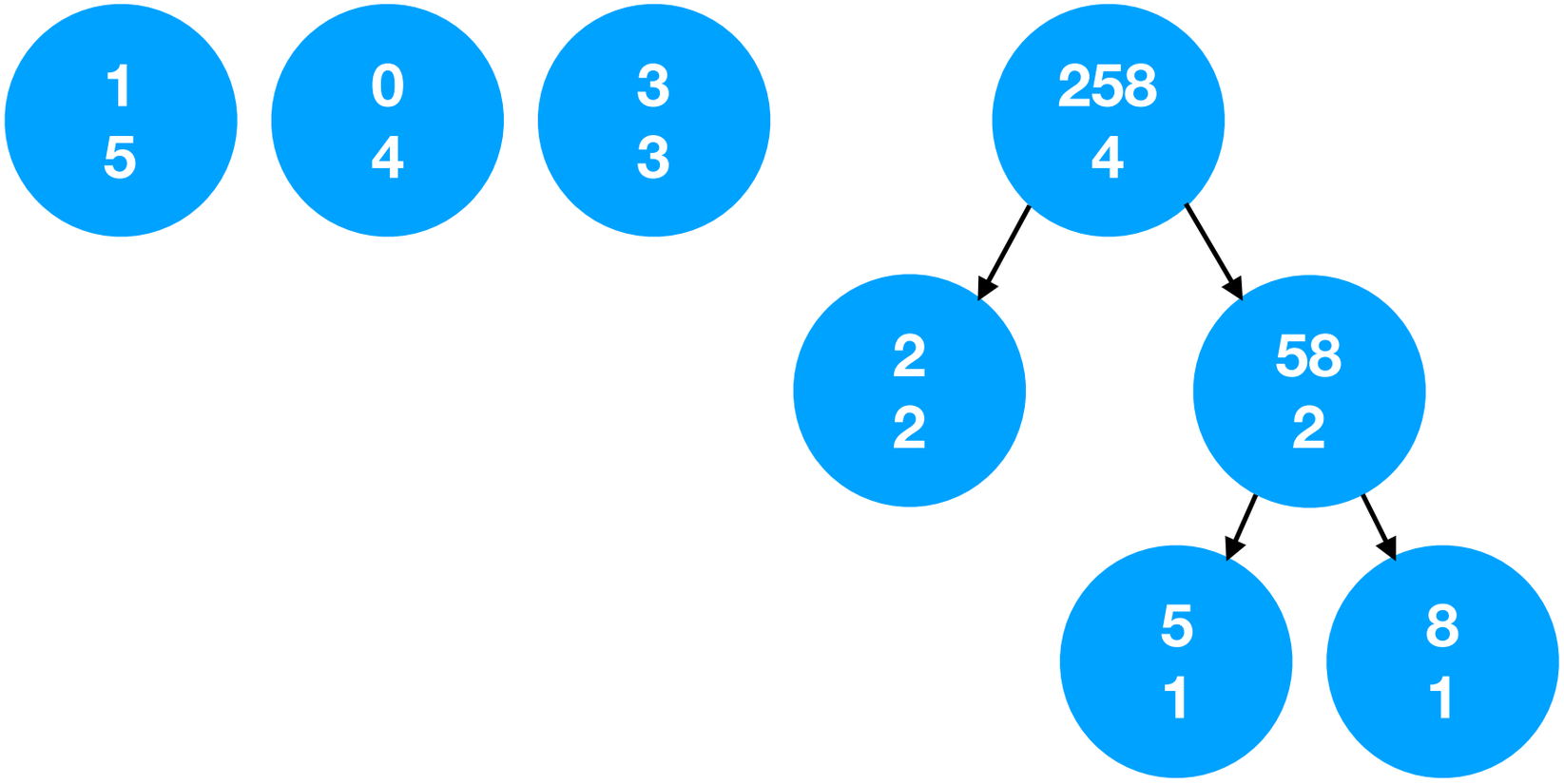

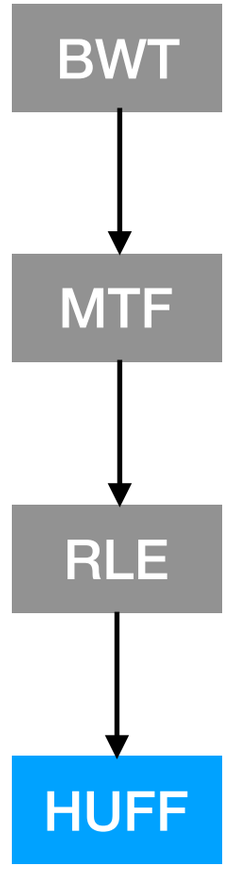

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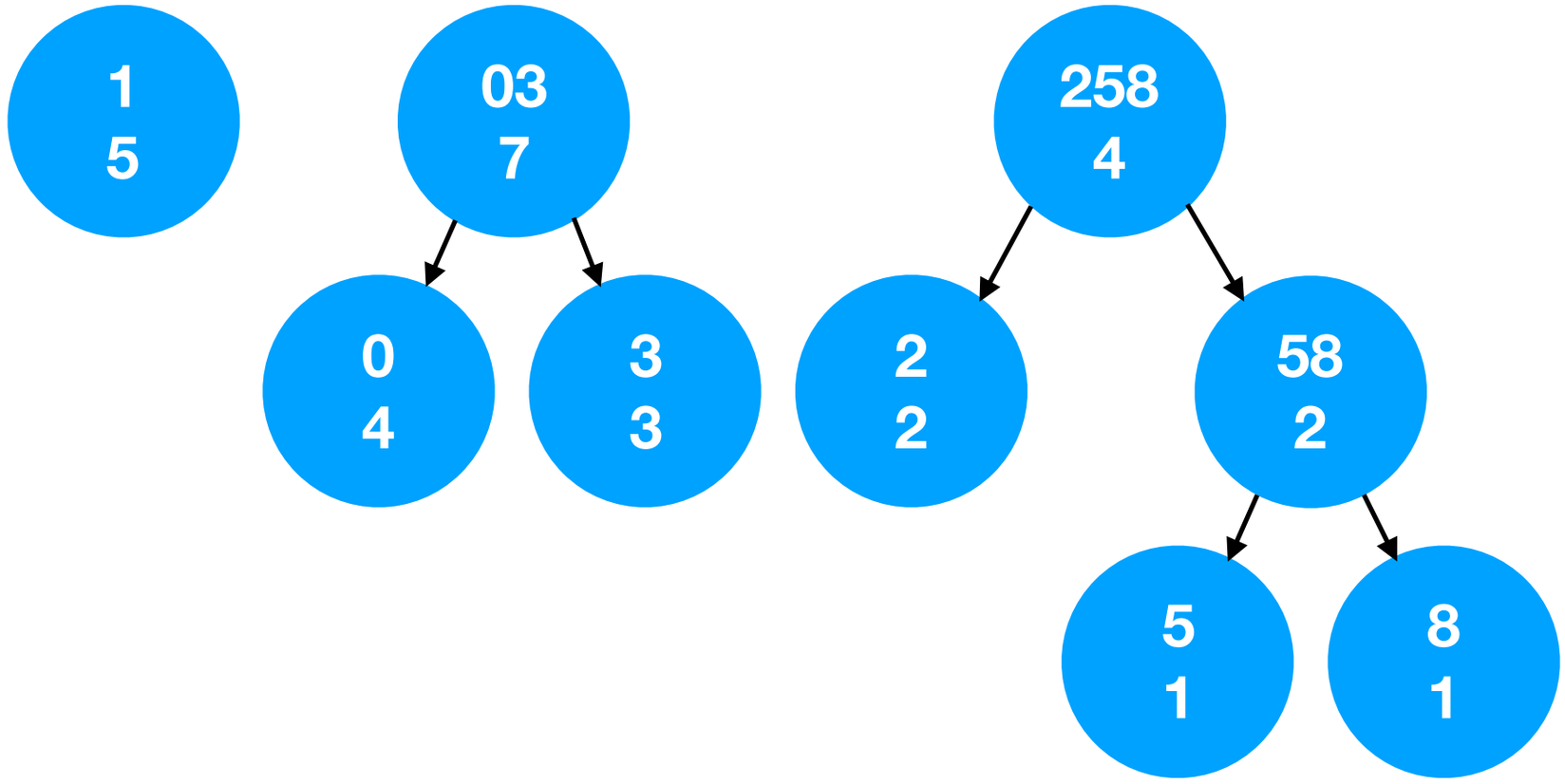

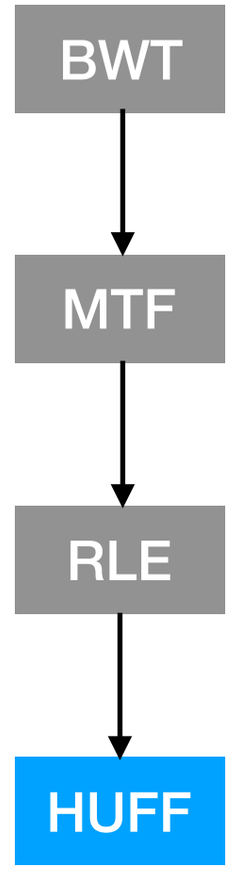

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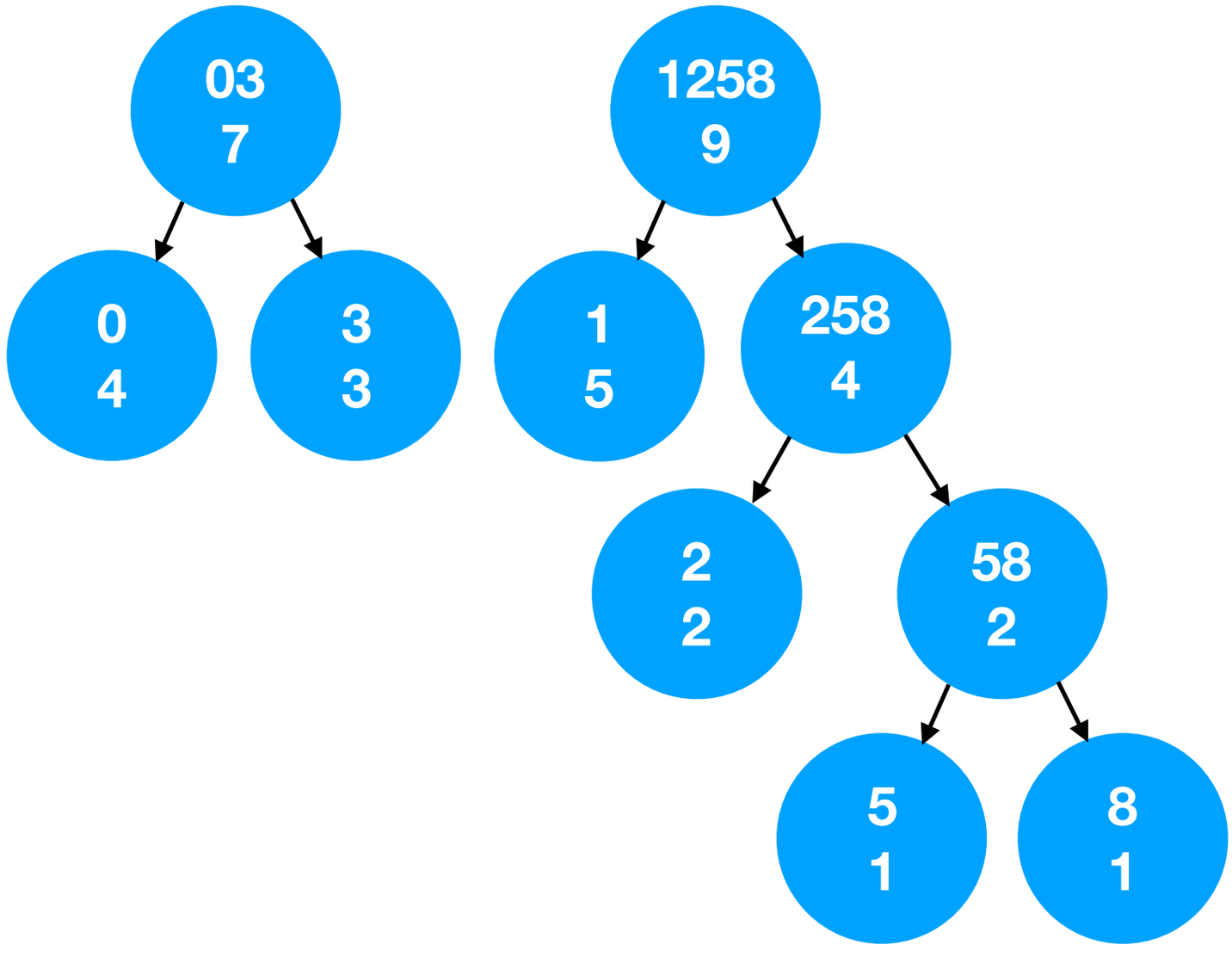

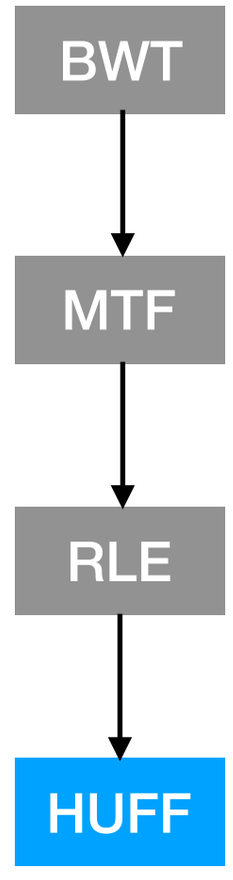

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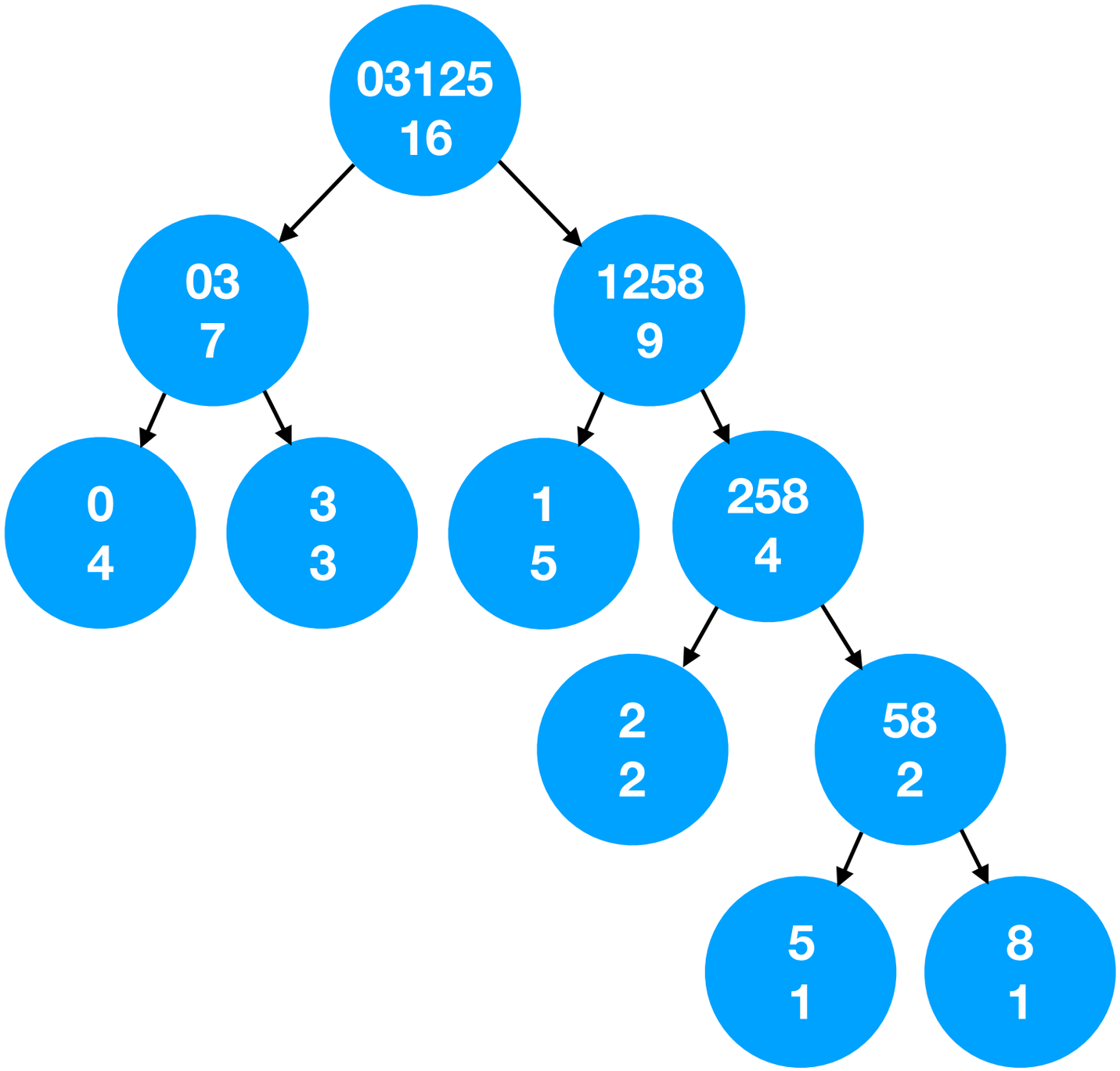

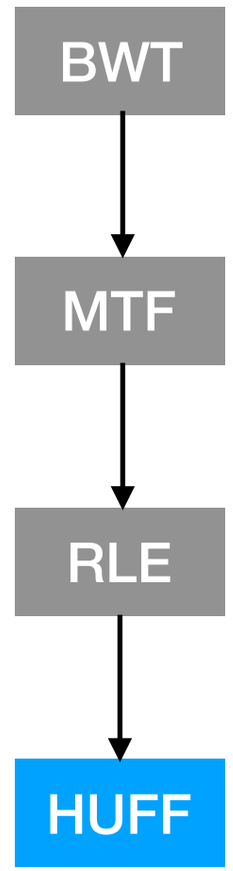

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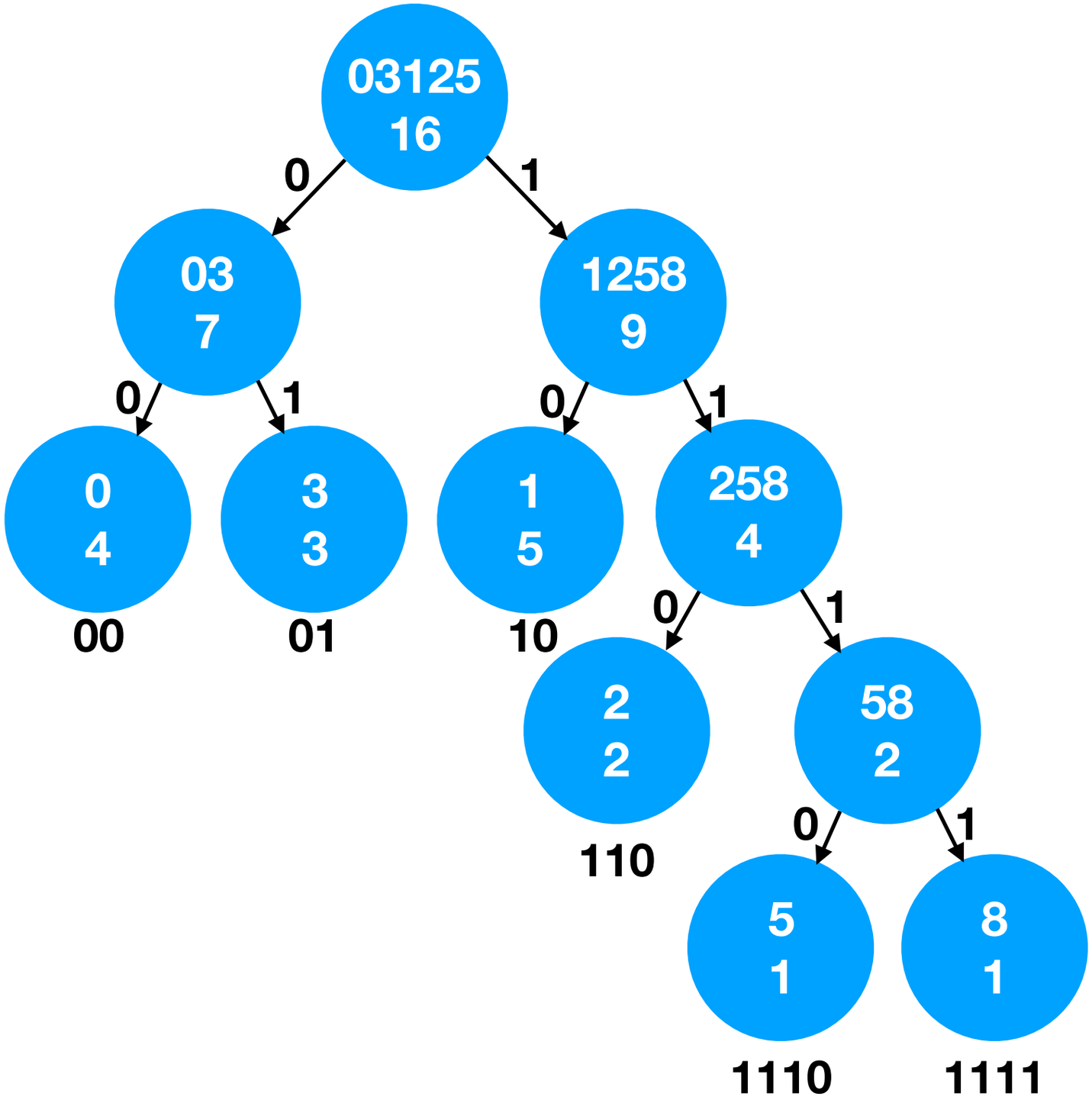

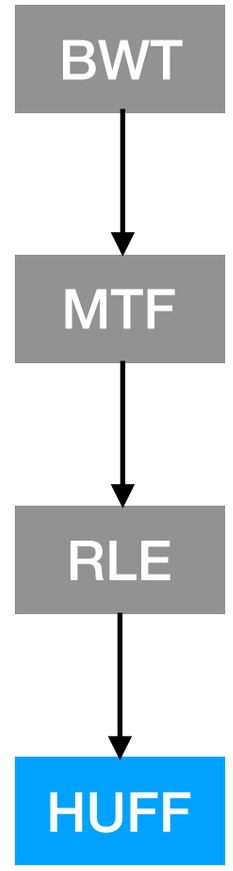

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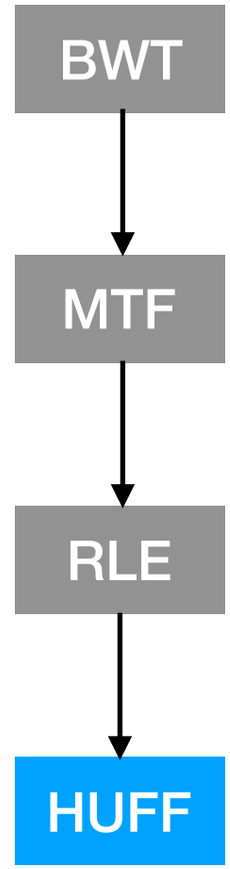

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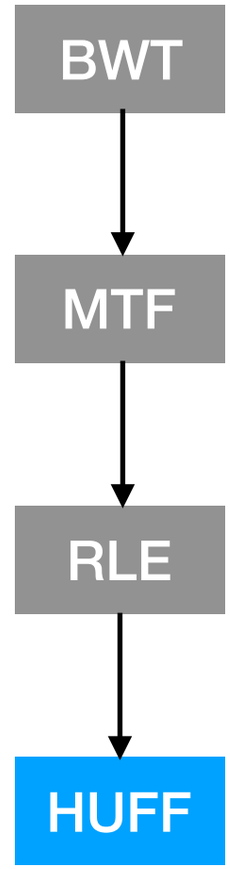

Huffman-Kodierung

- Eingabe: **3**1021102310531O8

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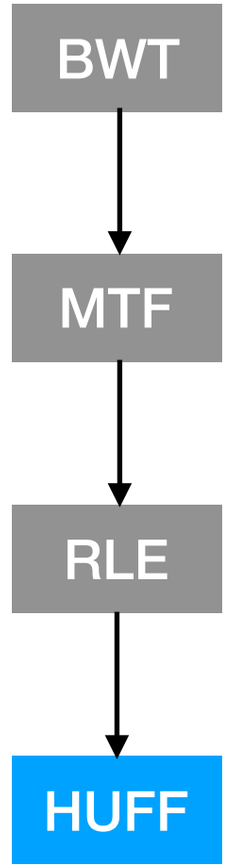

Huffman-Kodierung

- Eingabe: **3**1021102310531O8

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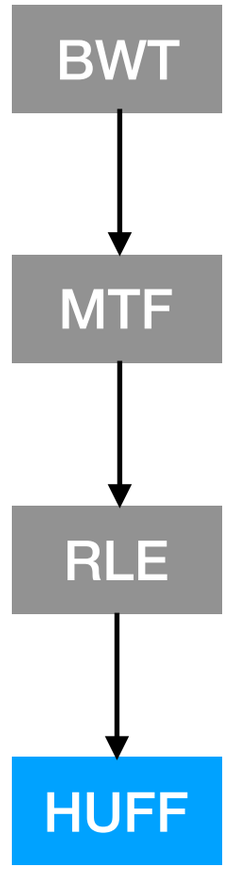
- Ausgabe: 01



Huffman-Kodierung

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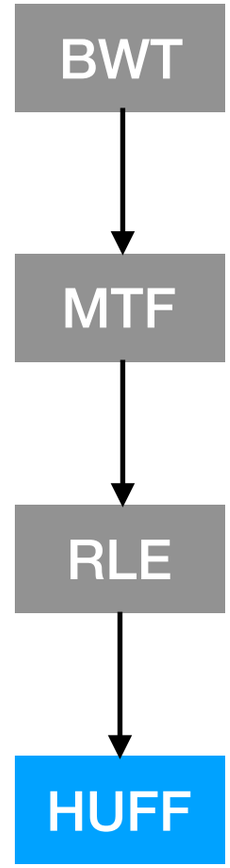
- Ausgabe: 01



Huffman-Kodierung

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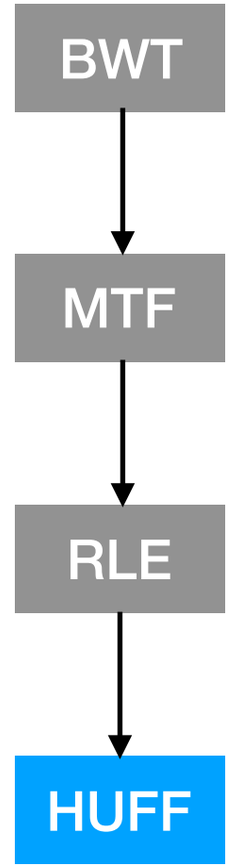
- Ausgabe: 01



Huffman-Kodierung

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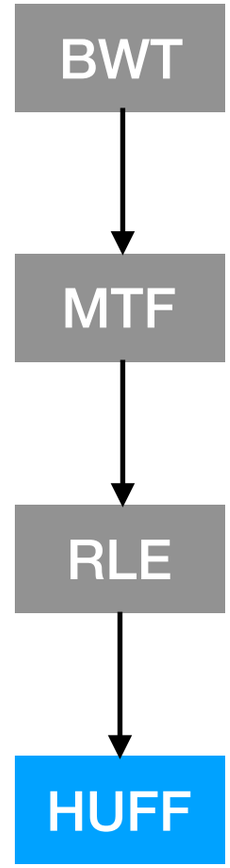
- Ausgabe: 0110



Huffman-Kodierung

- Eingabe: 31021102310531O8

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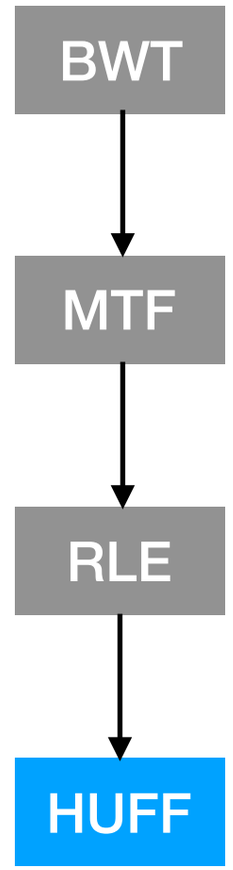

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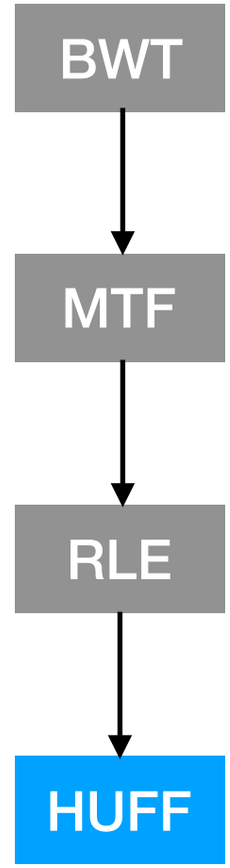
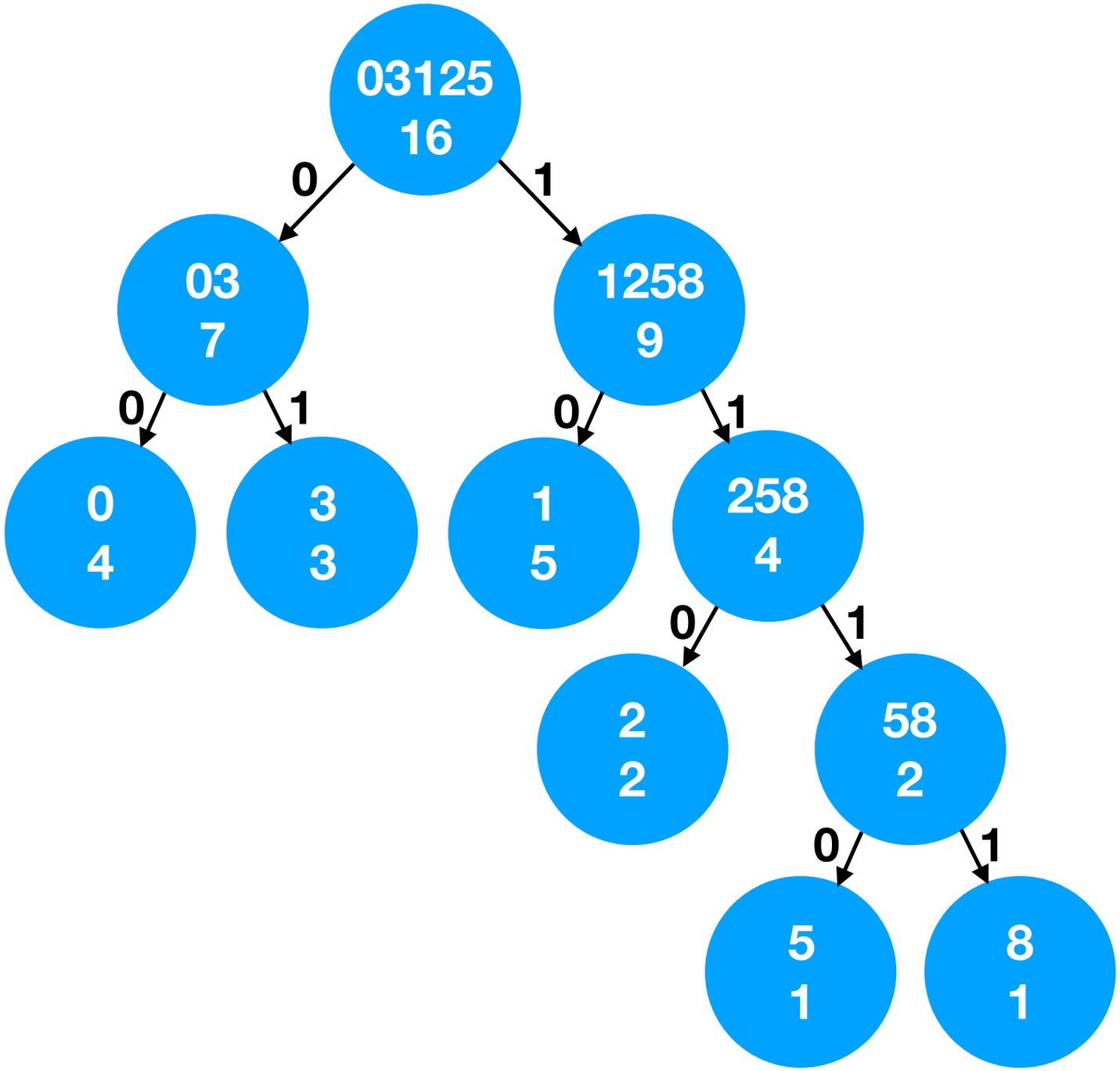
Huffman-Kodierung

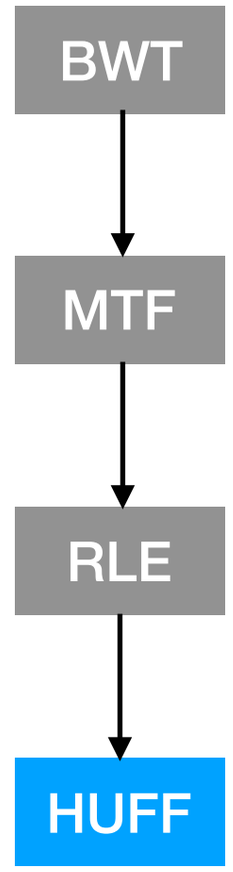
- Auch der Baum muss gespeichert werden



Huffman-Kodierung

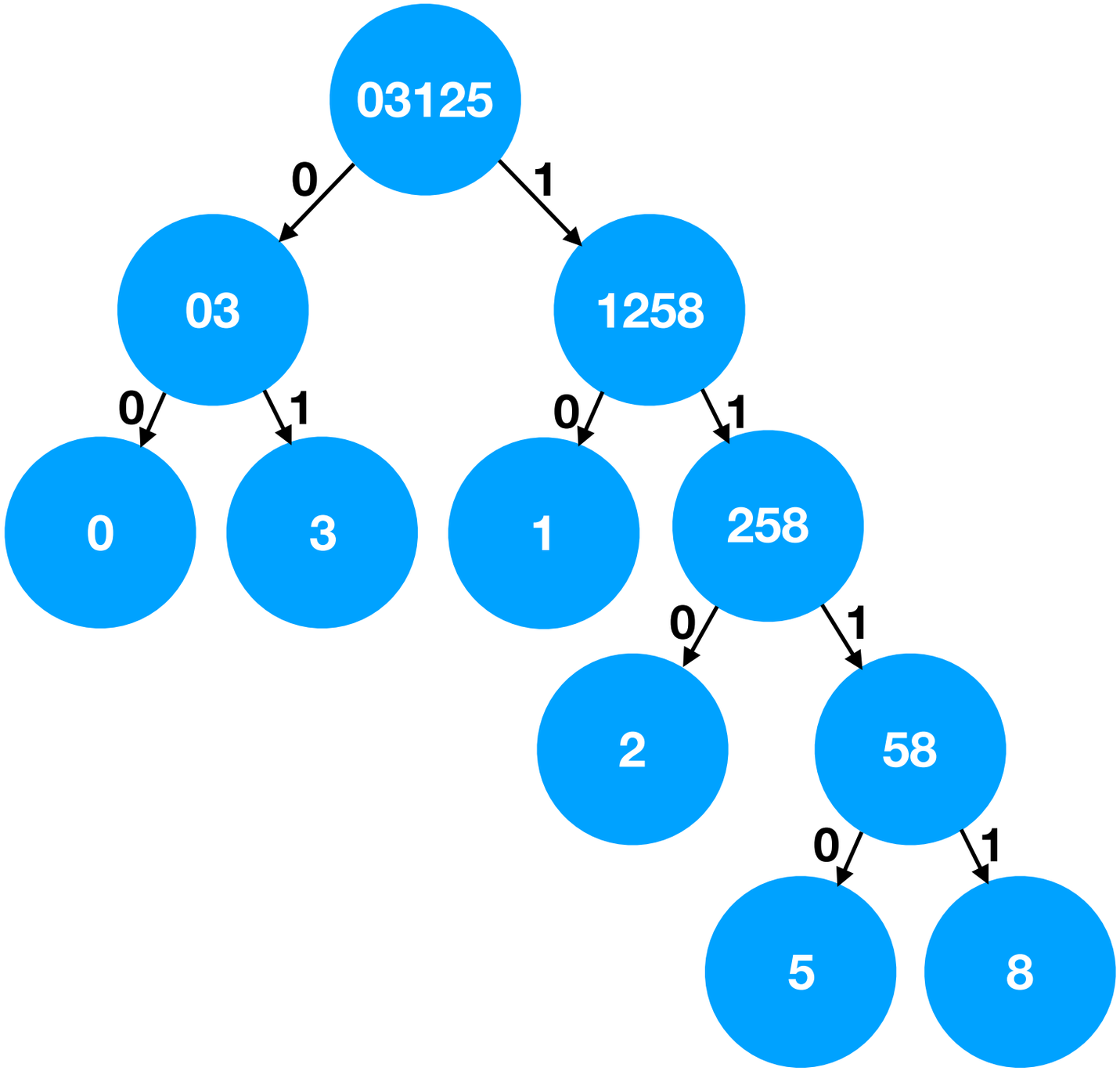
- Auch der Baum muss gespeichert werden

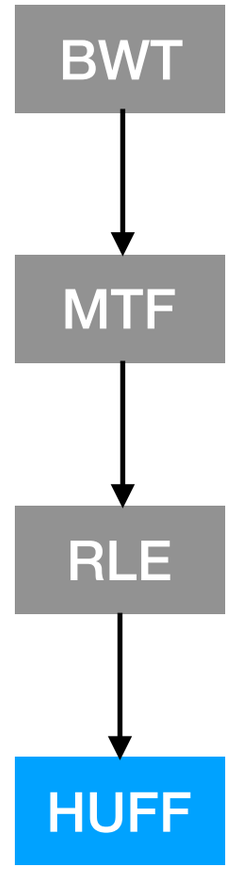




Huffman-Kodierung

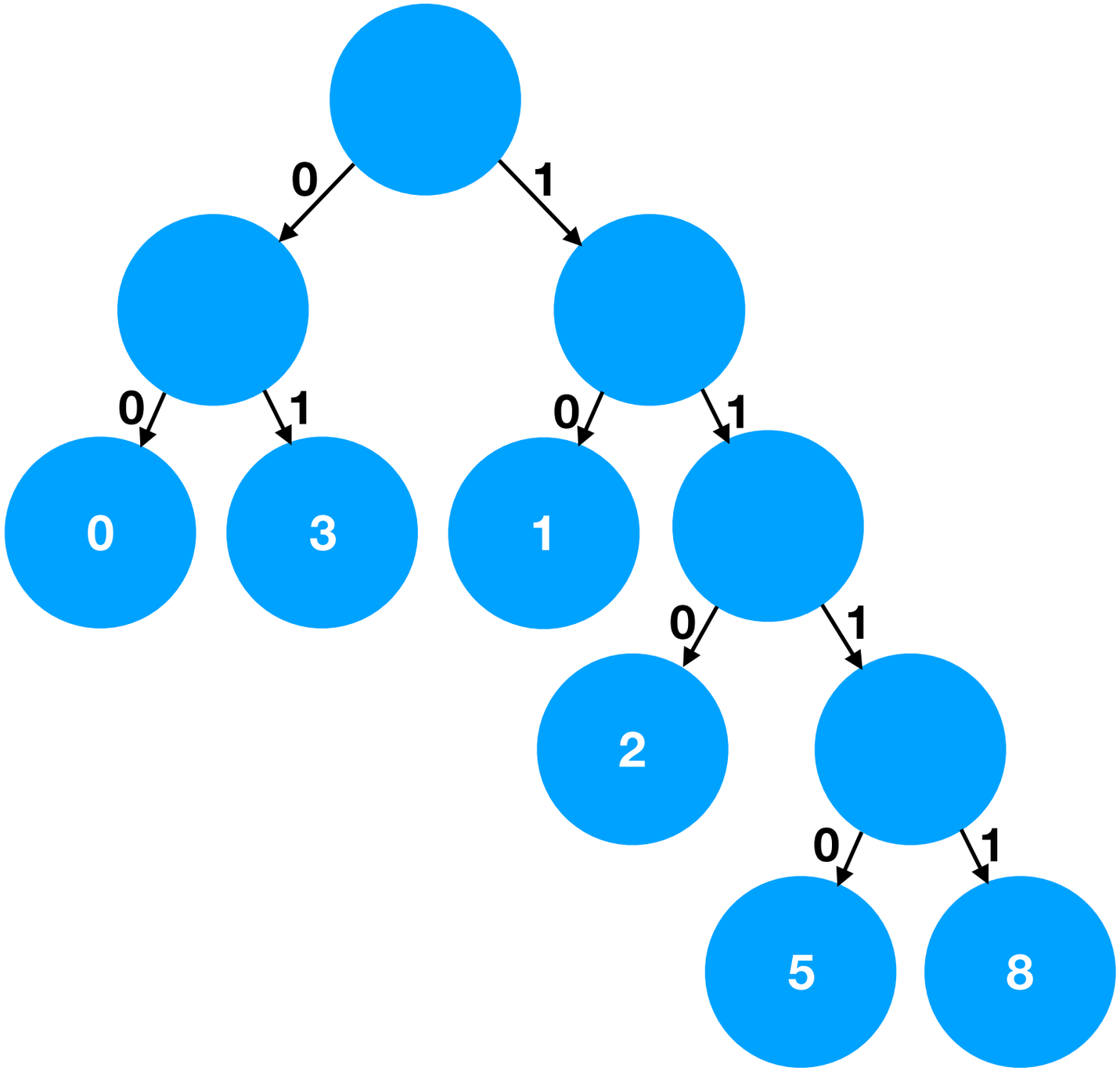
- Auch der Baum muss gespeichert werden

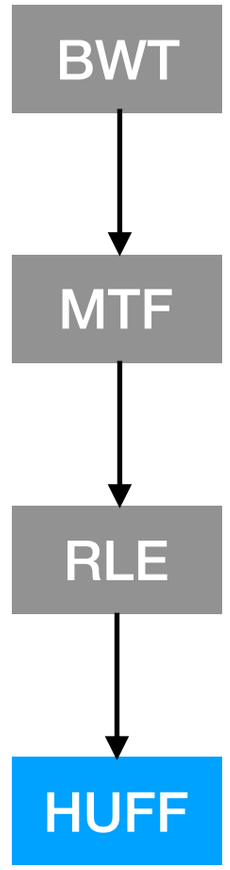




Huffman-Kodierung

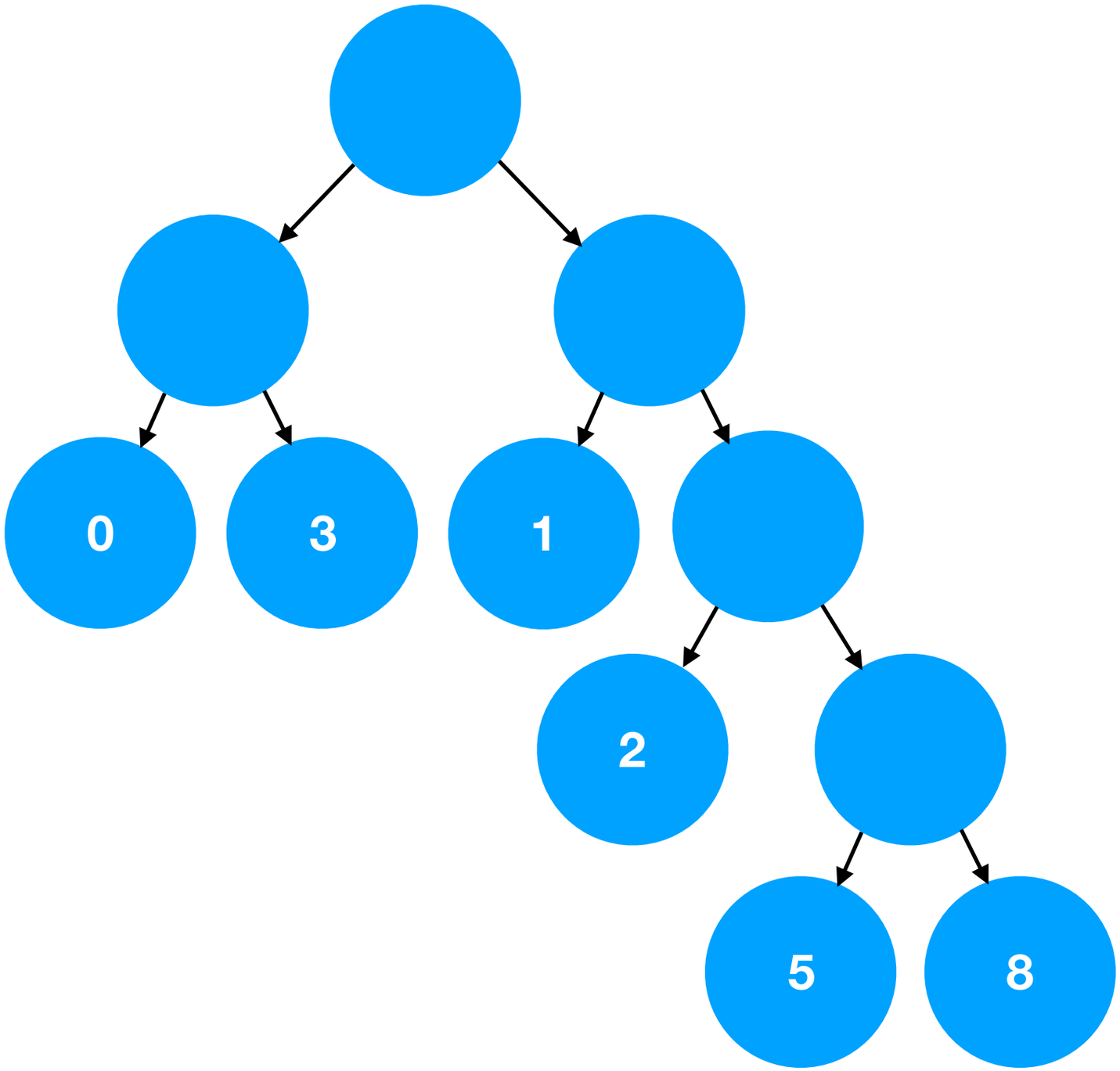
- Auch der Baum muss gespeichert werden

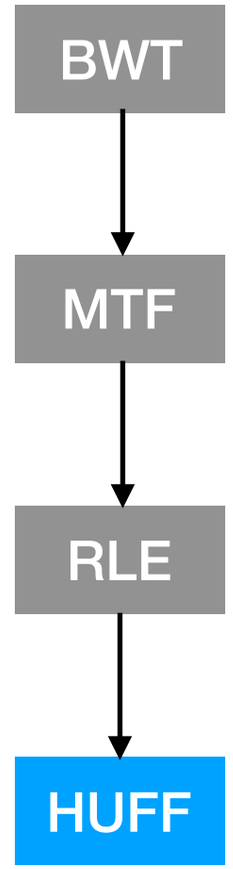




Huffman-Kodierung

- Auch der Baum muss gespeichert werden





Huffman-Kodierung

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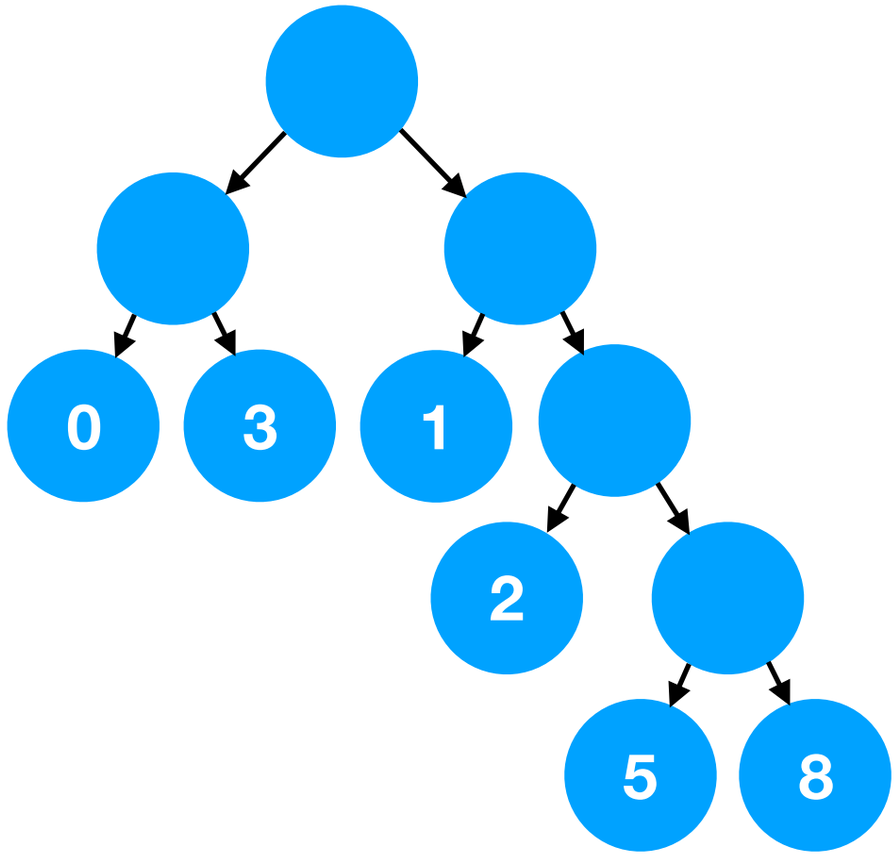
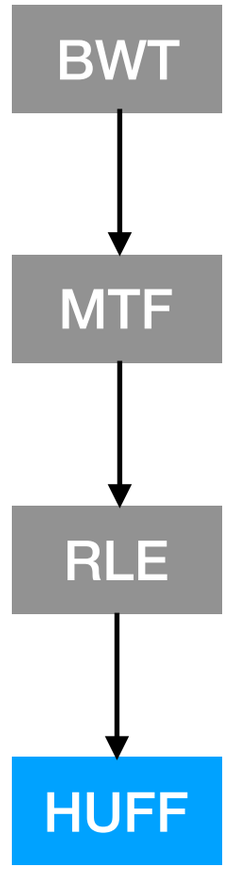
Blatt: 1 und der Wert





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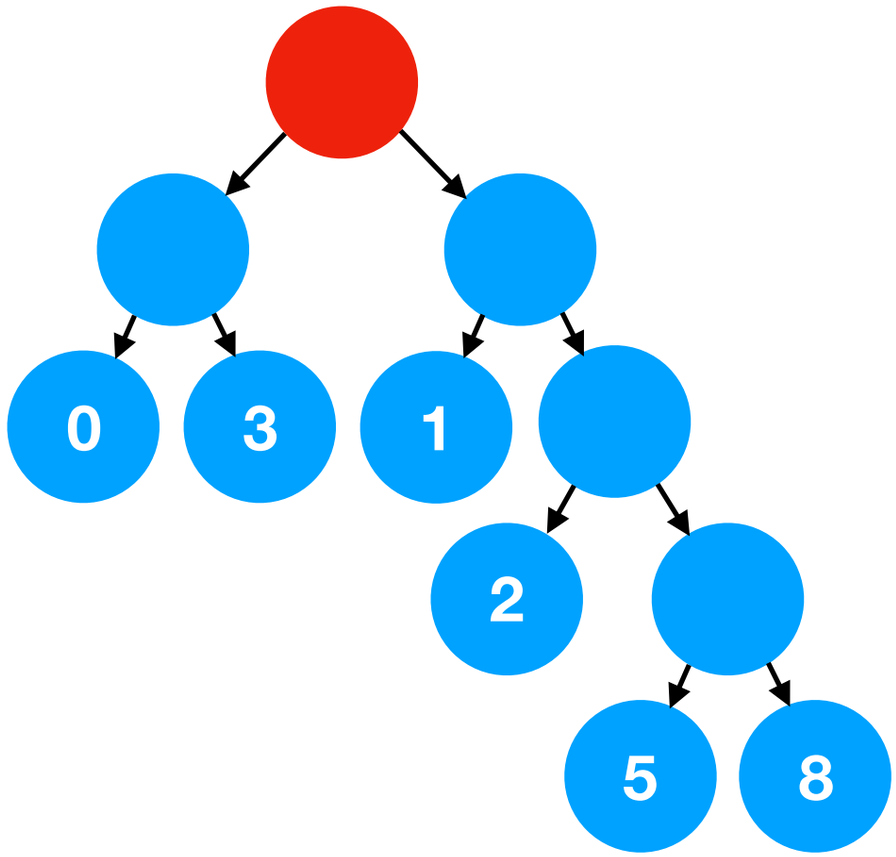

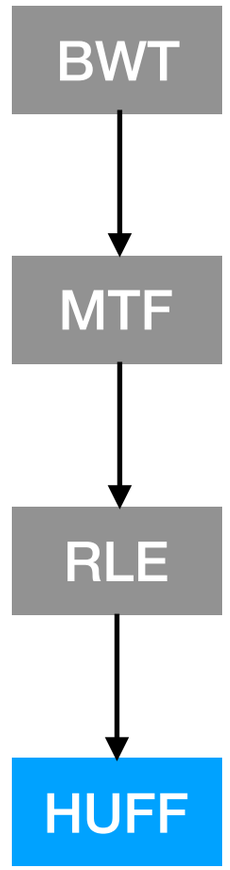

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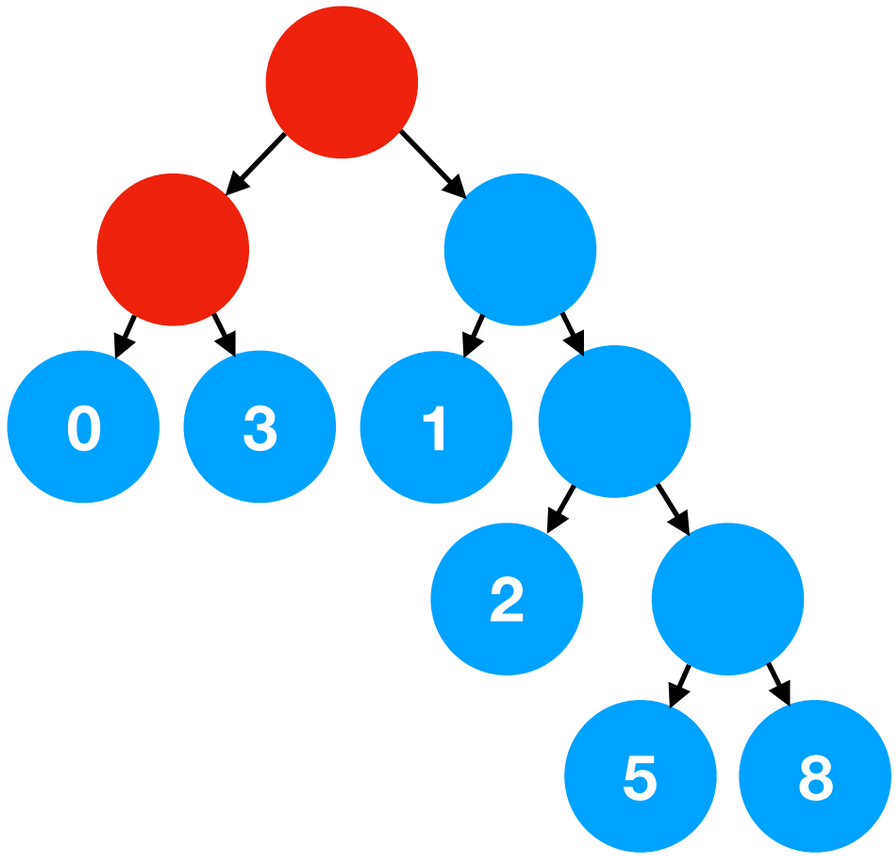

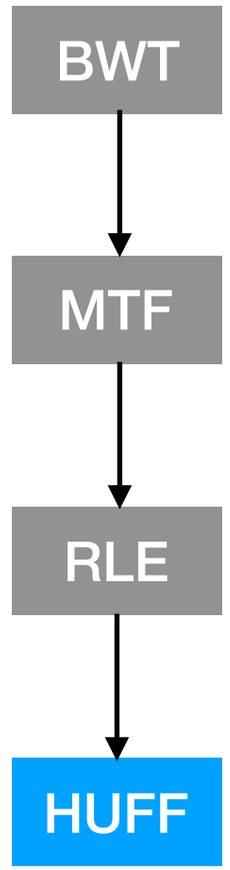

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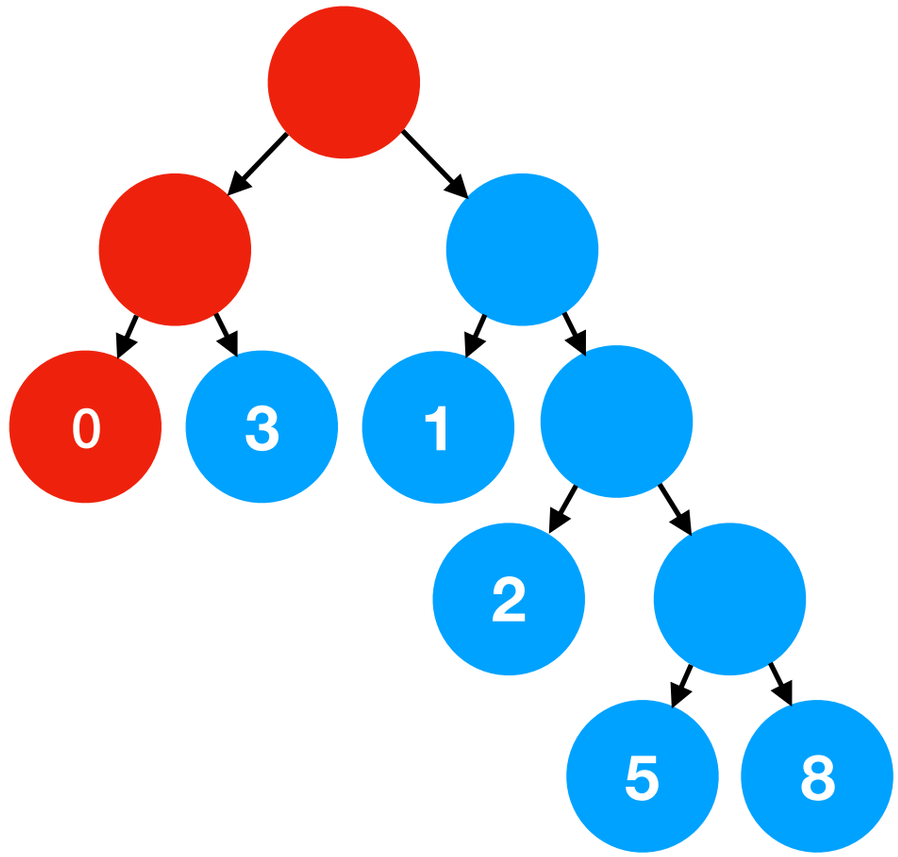

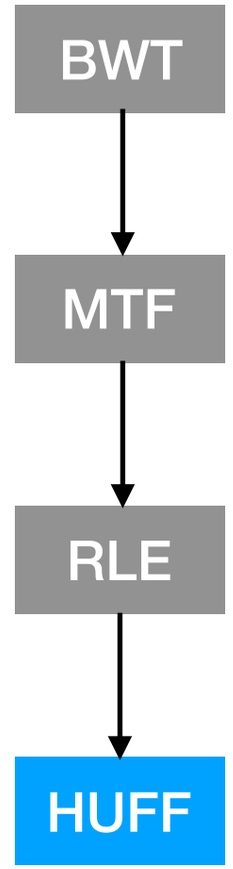

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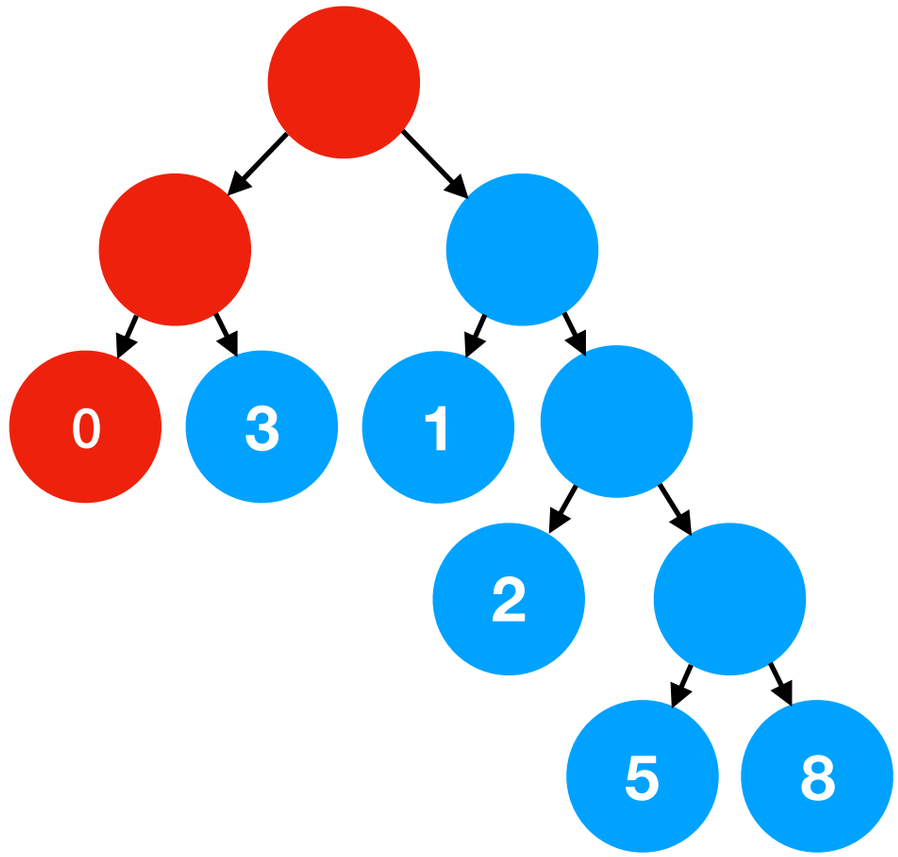

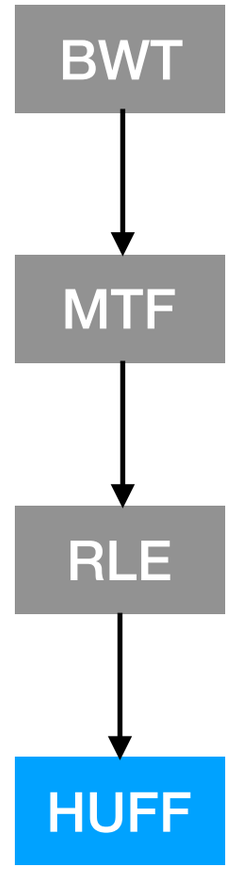

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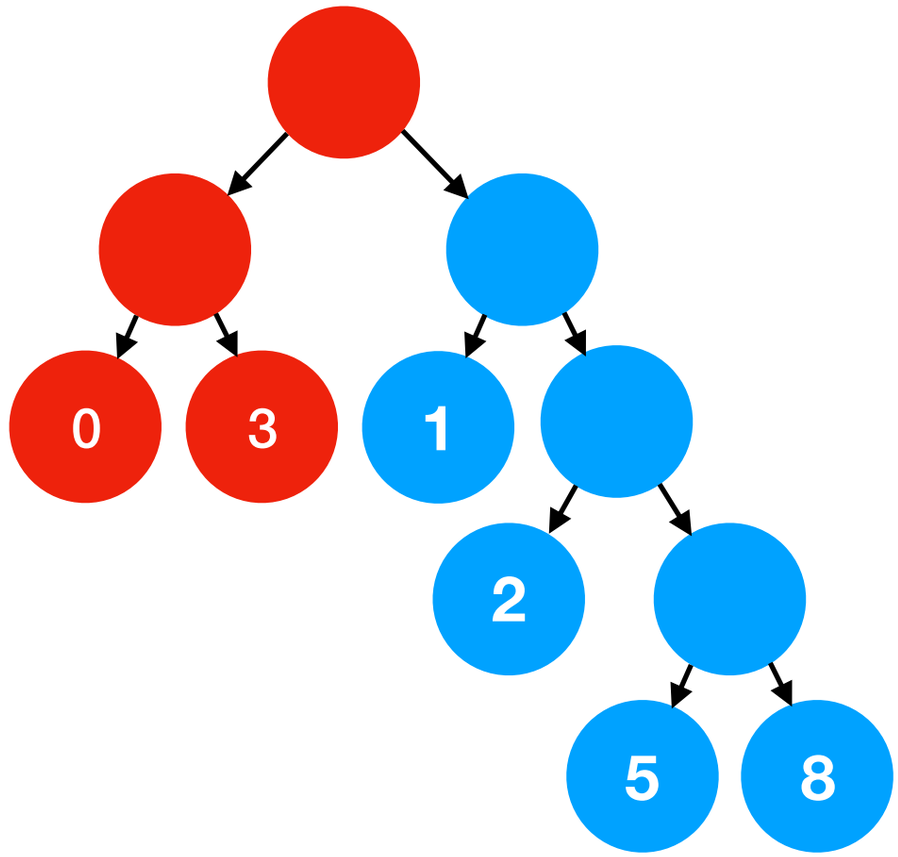

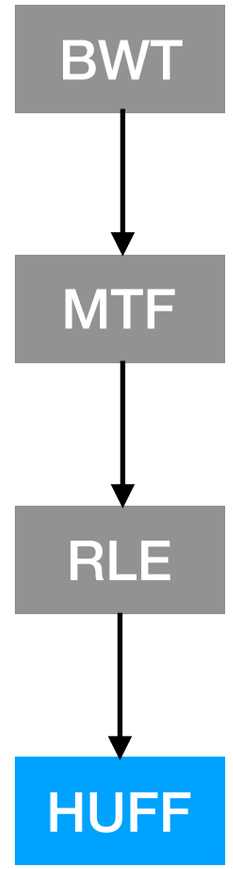

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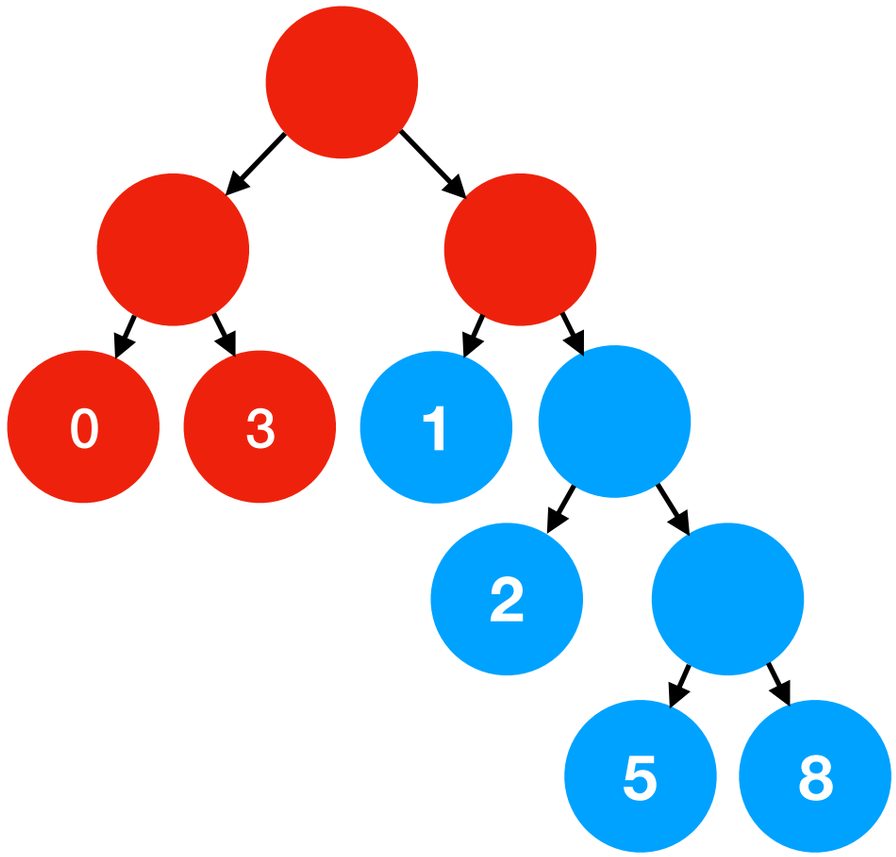

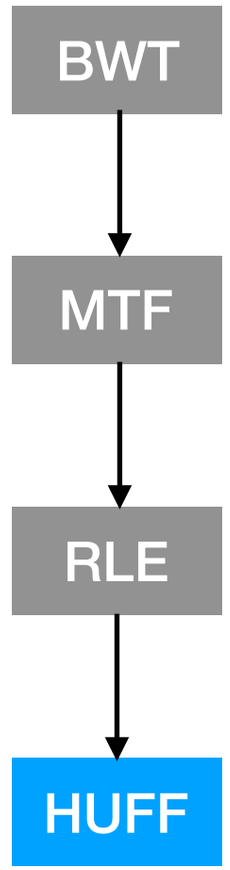

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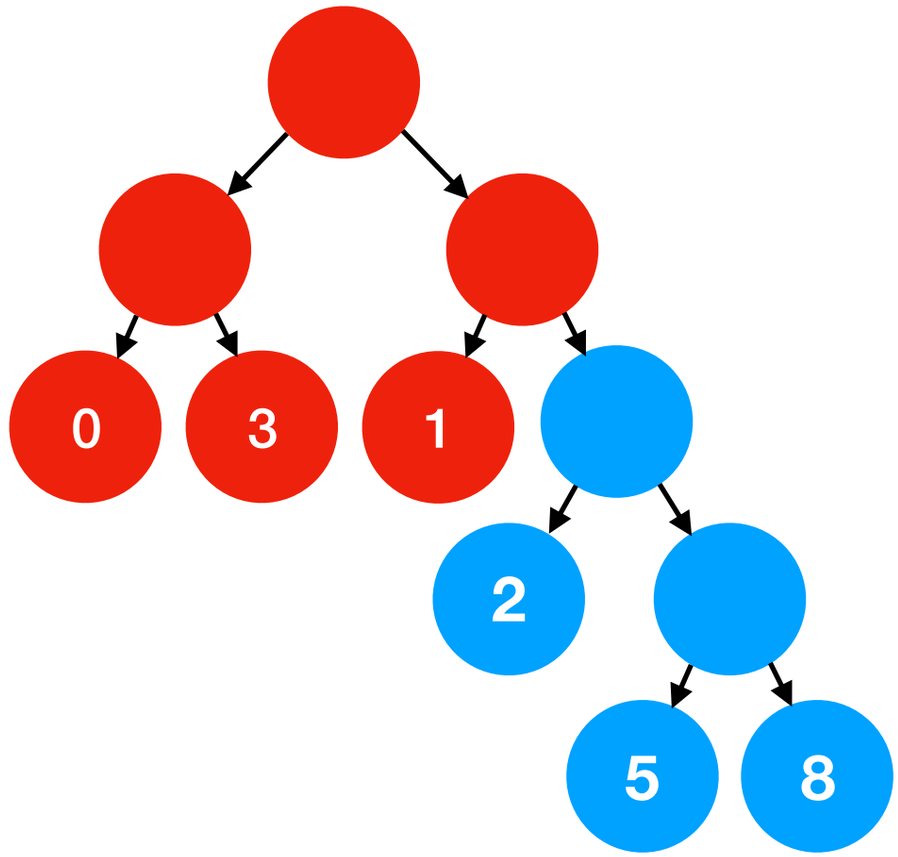

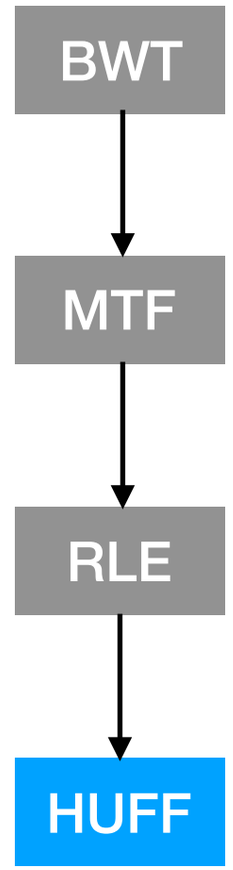

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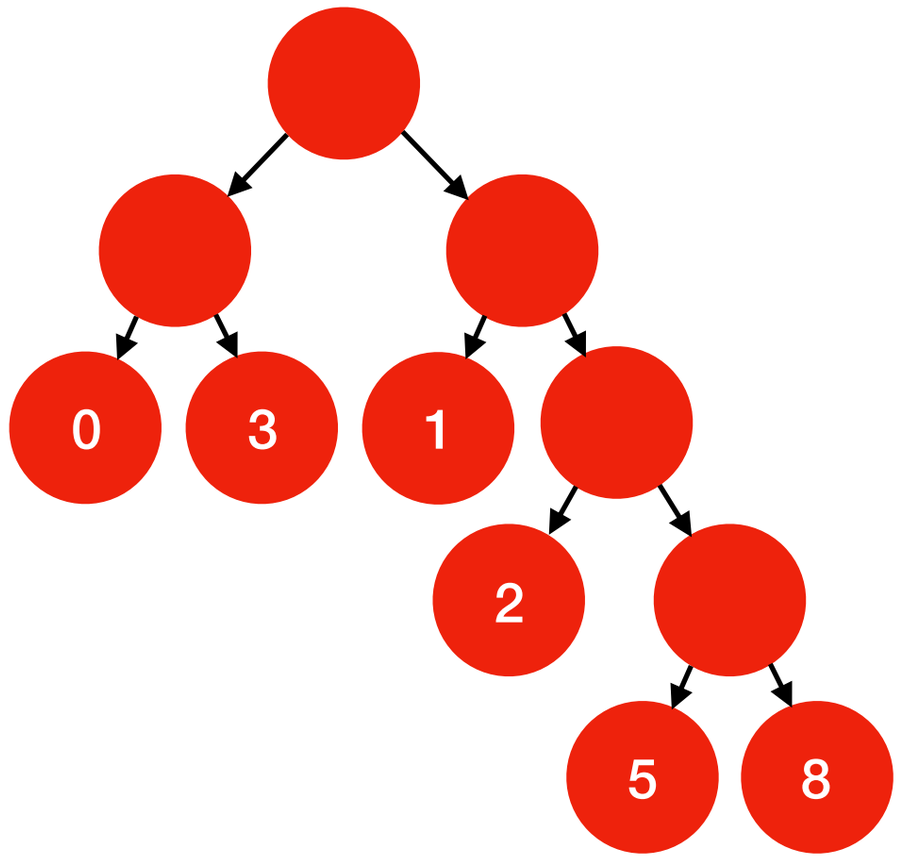

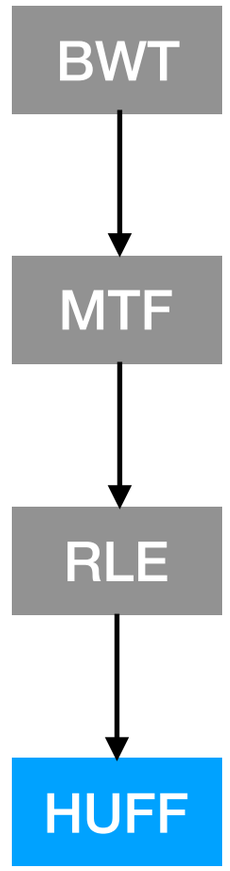

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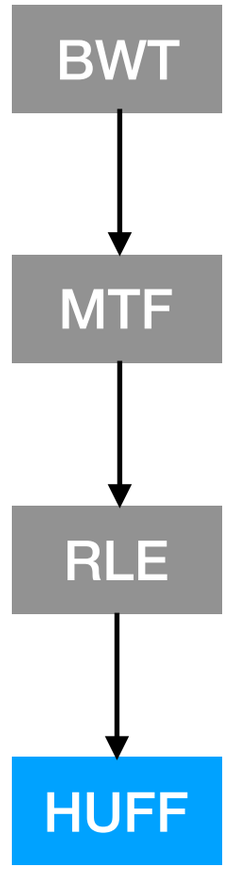

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- Eingabe:

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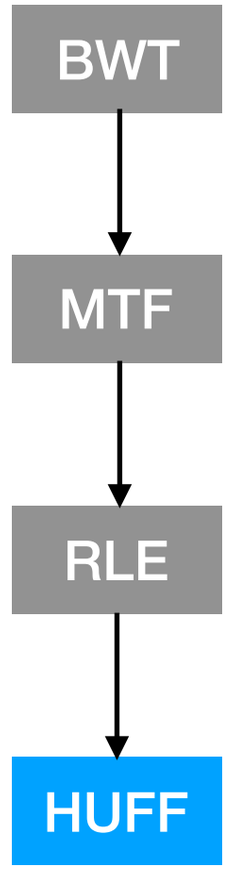

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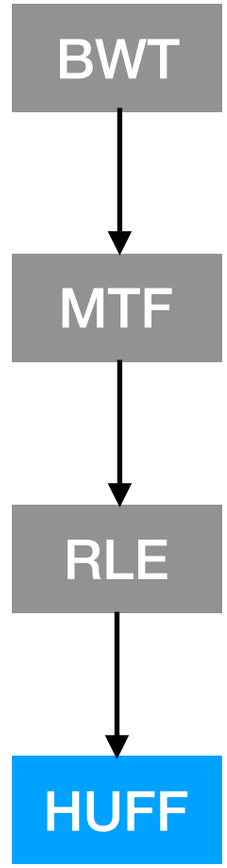

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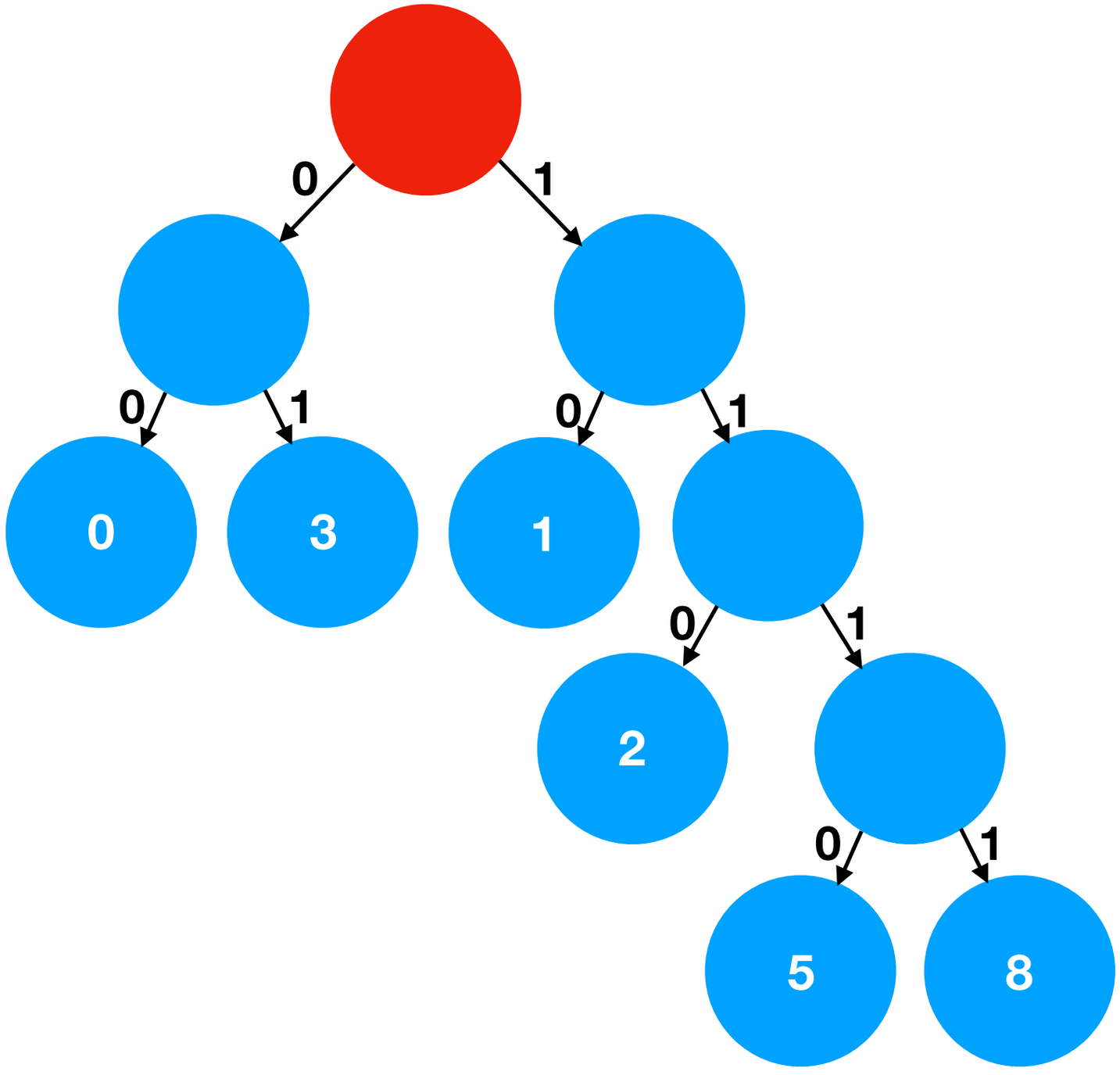

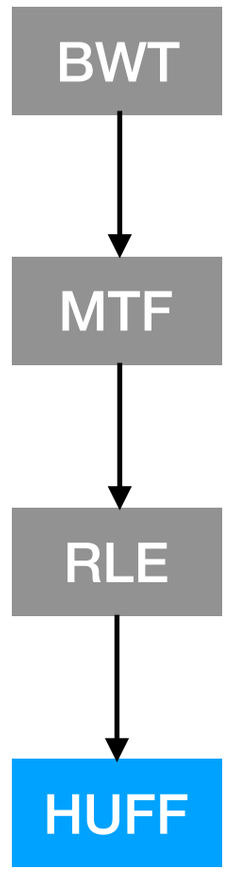

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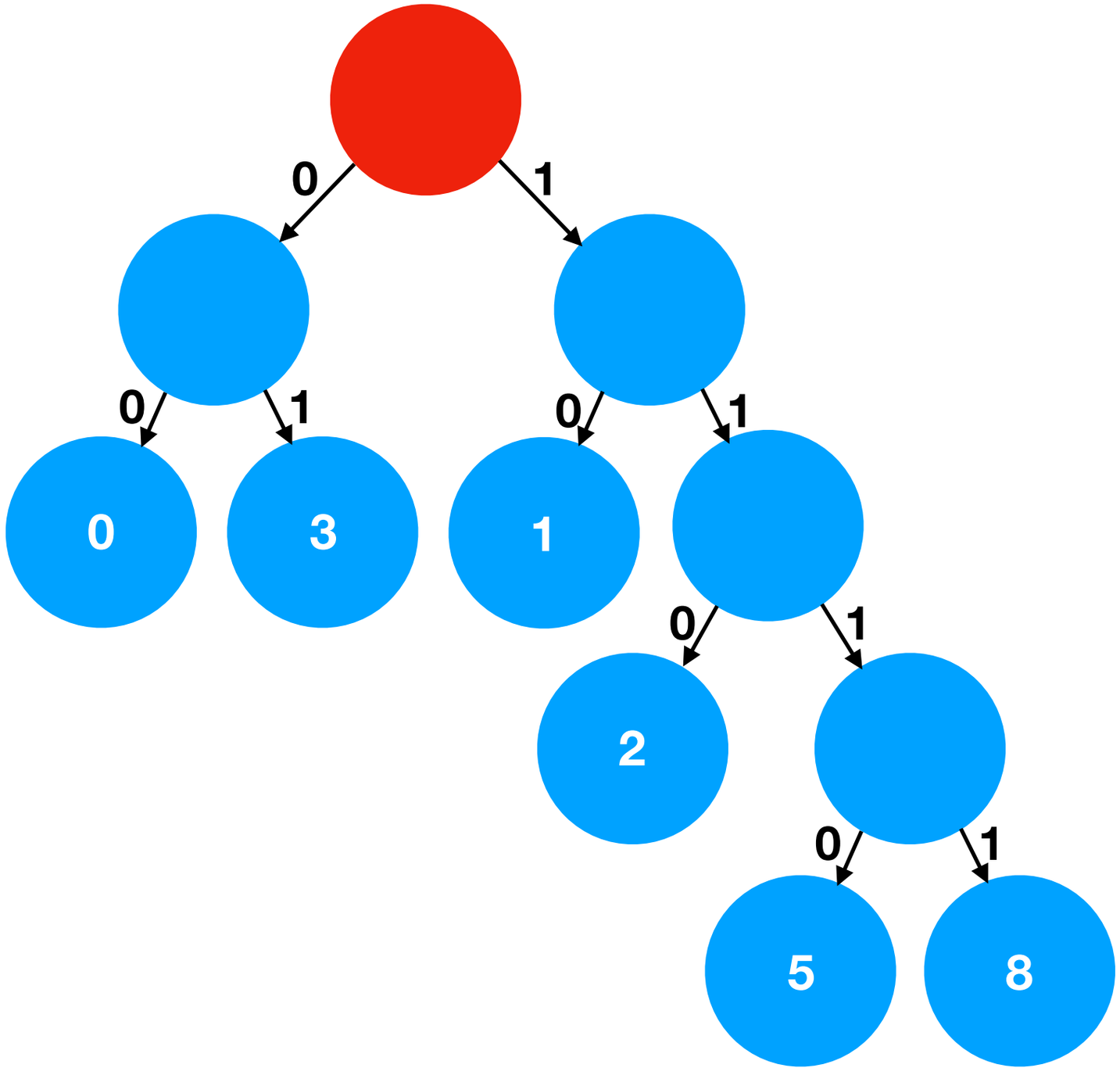

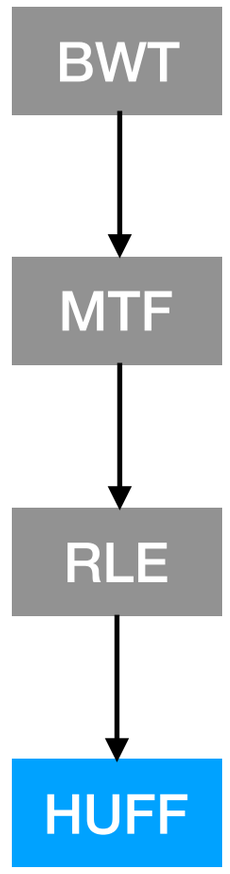

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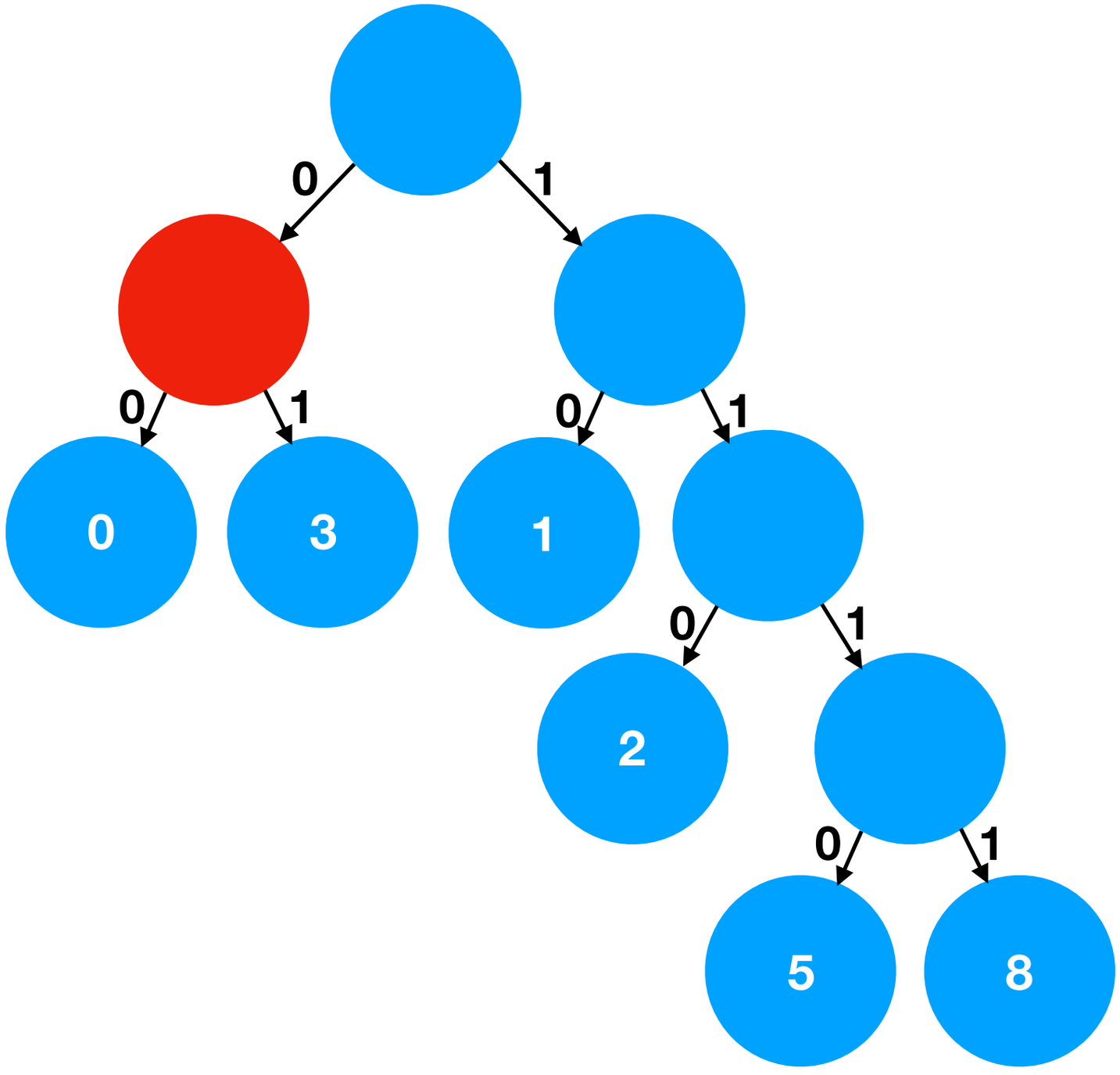

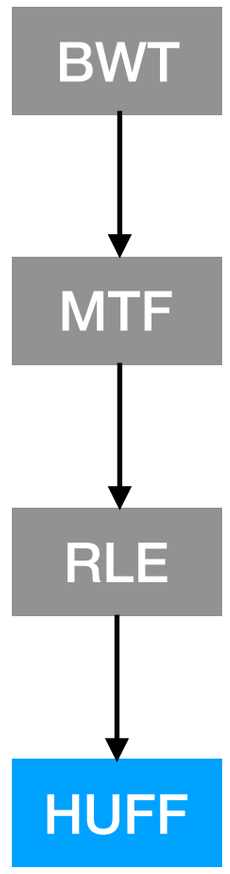

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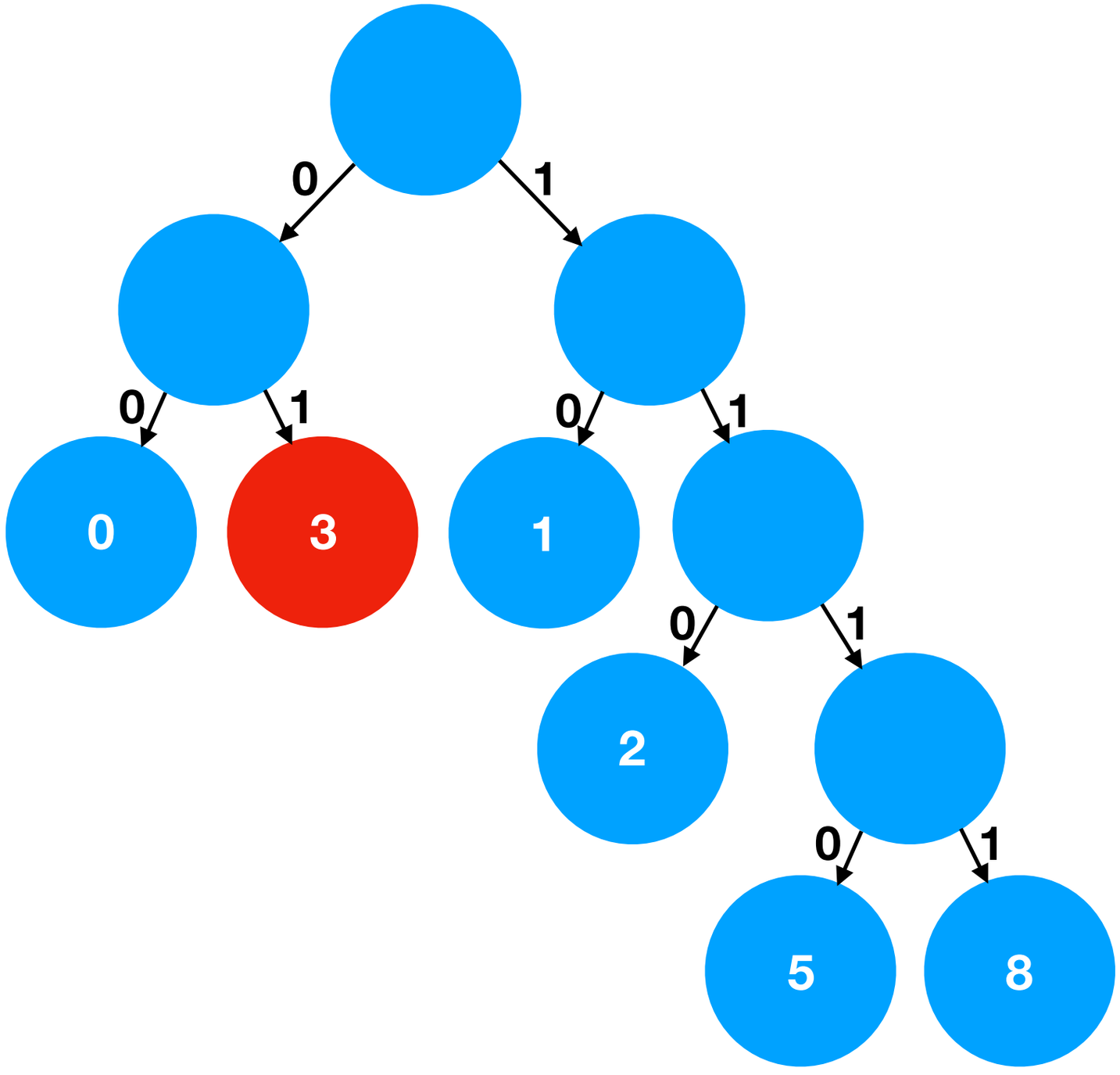

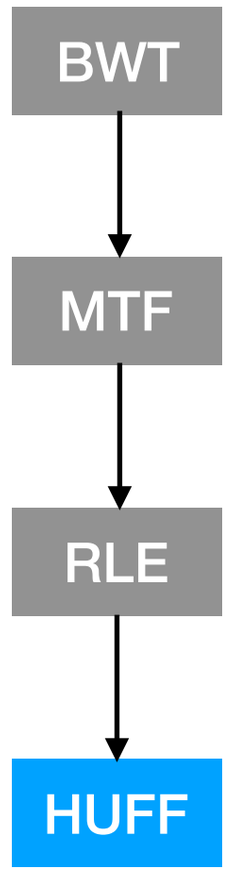

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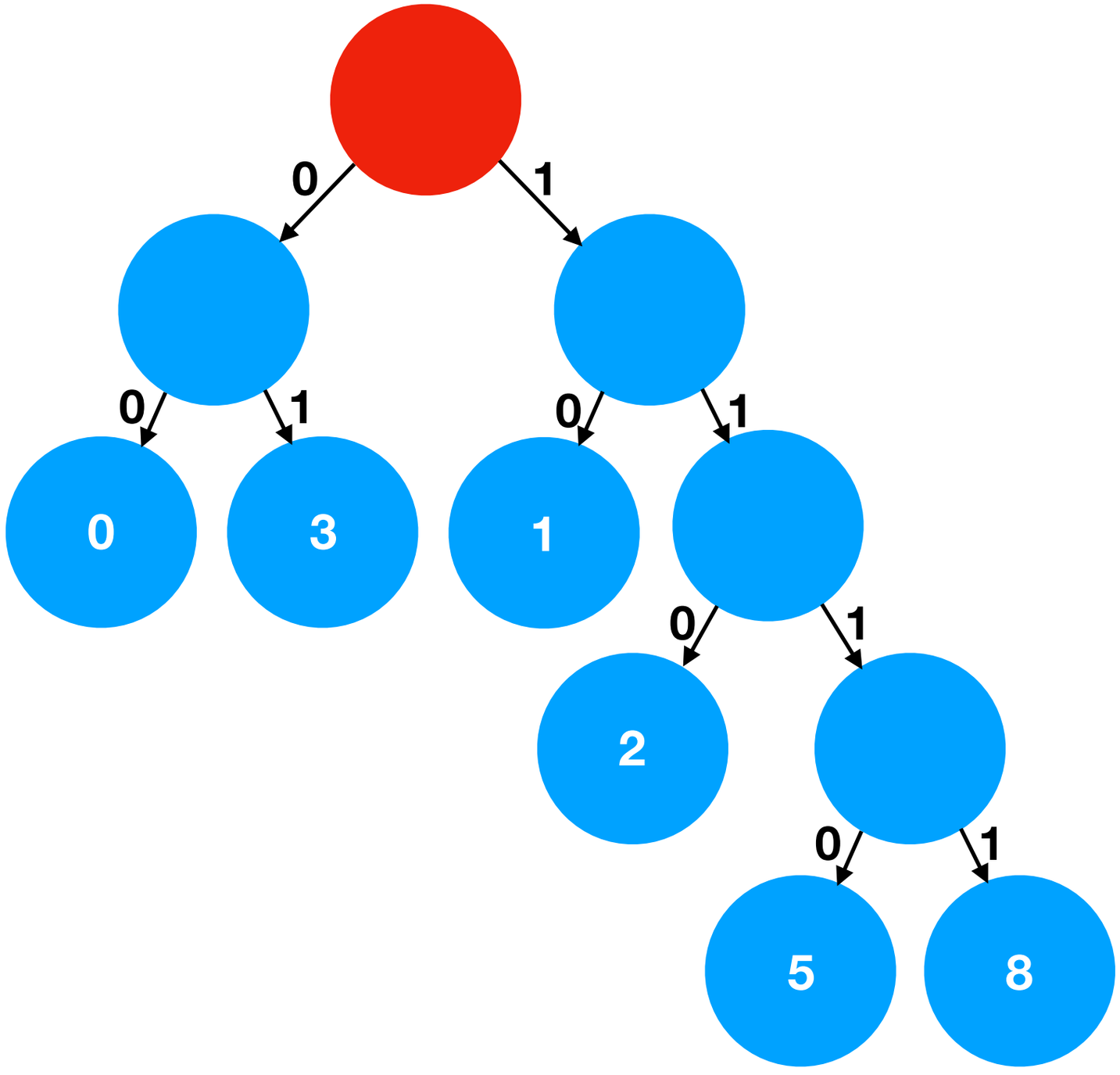

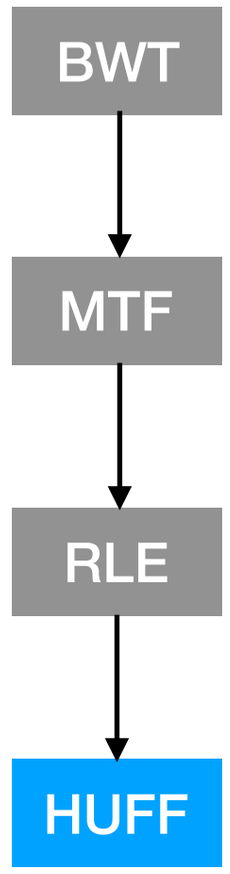

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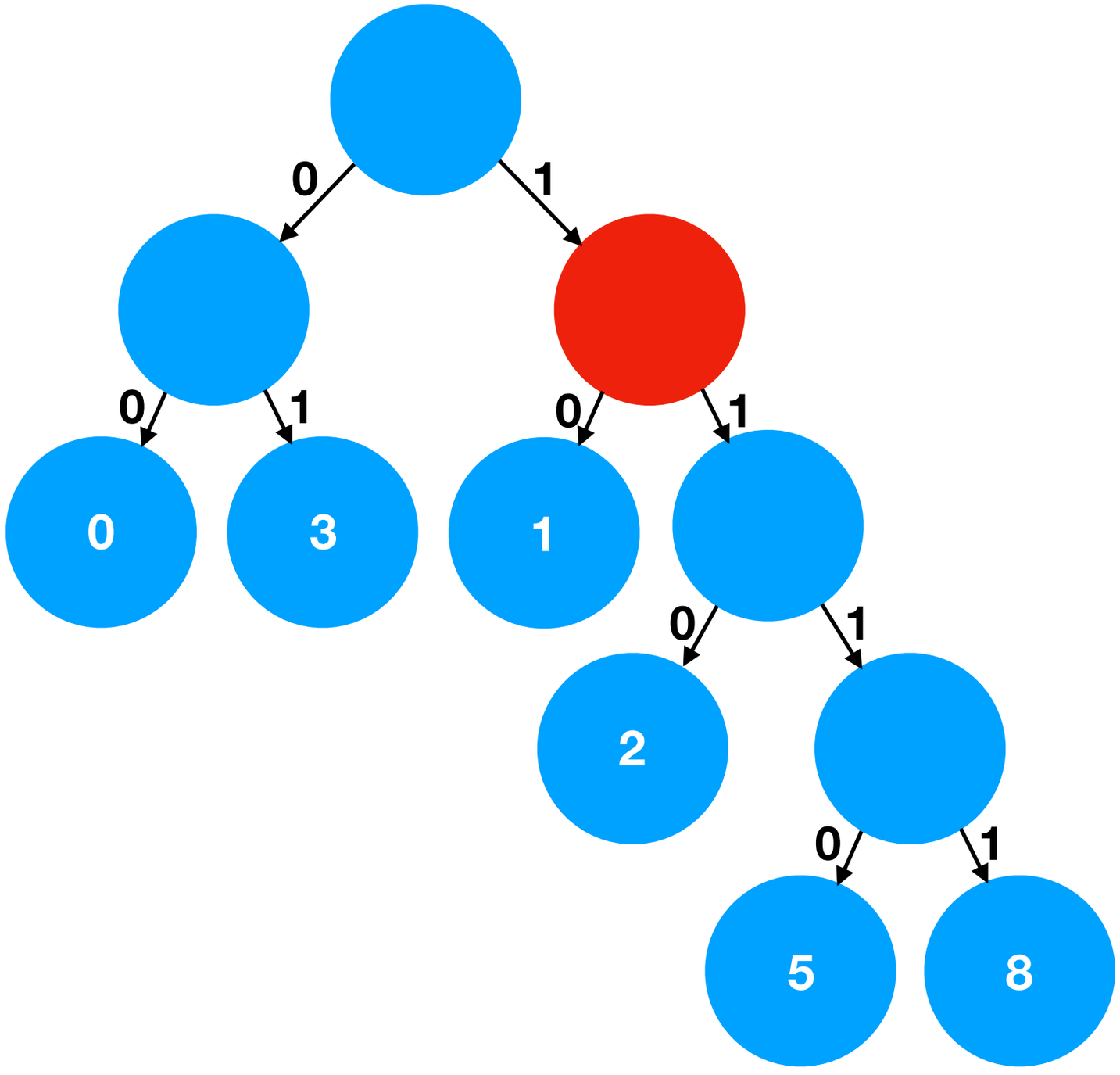

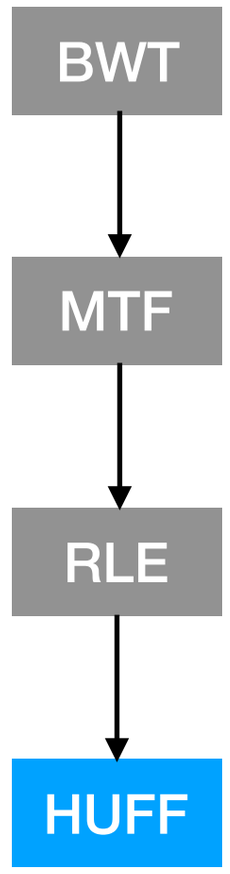

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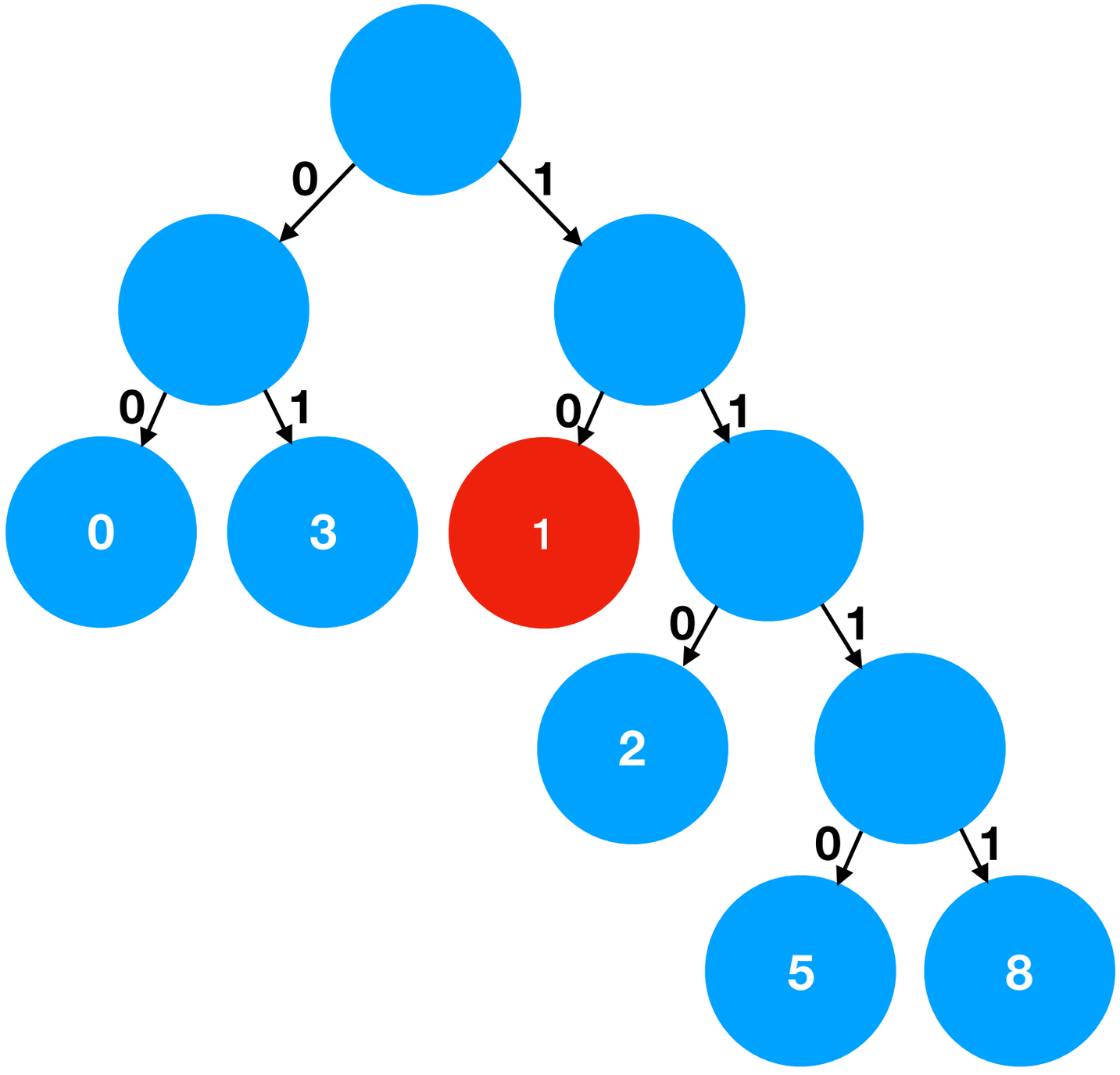

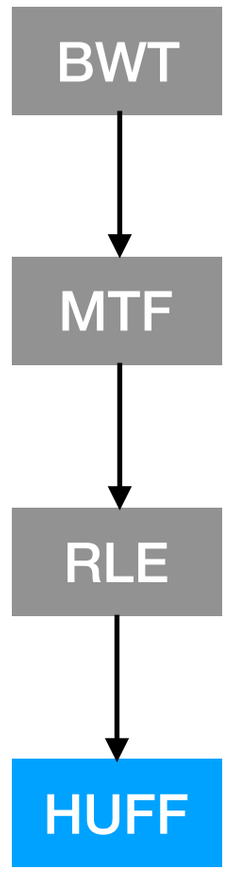

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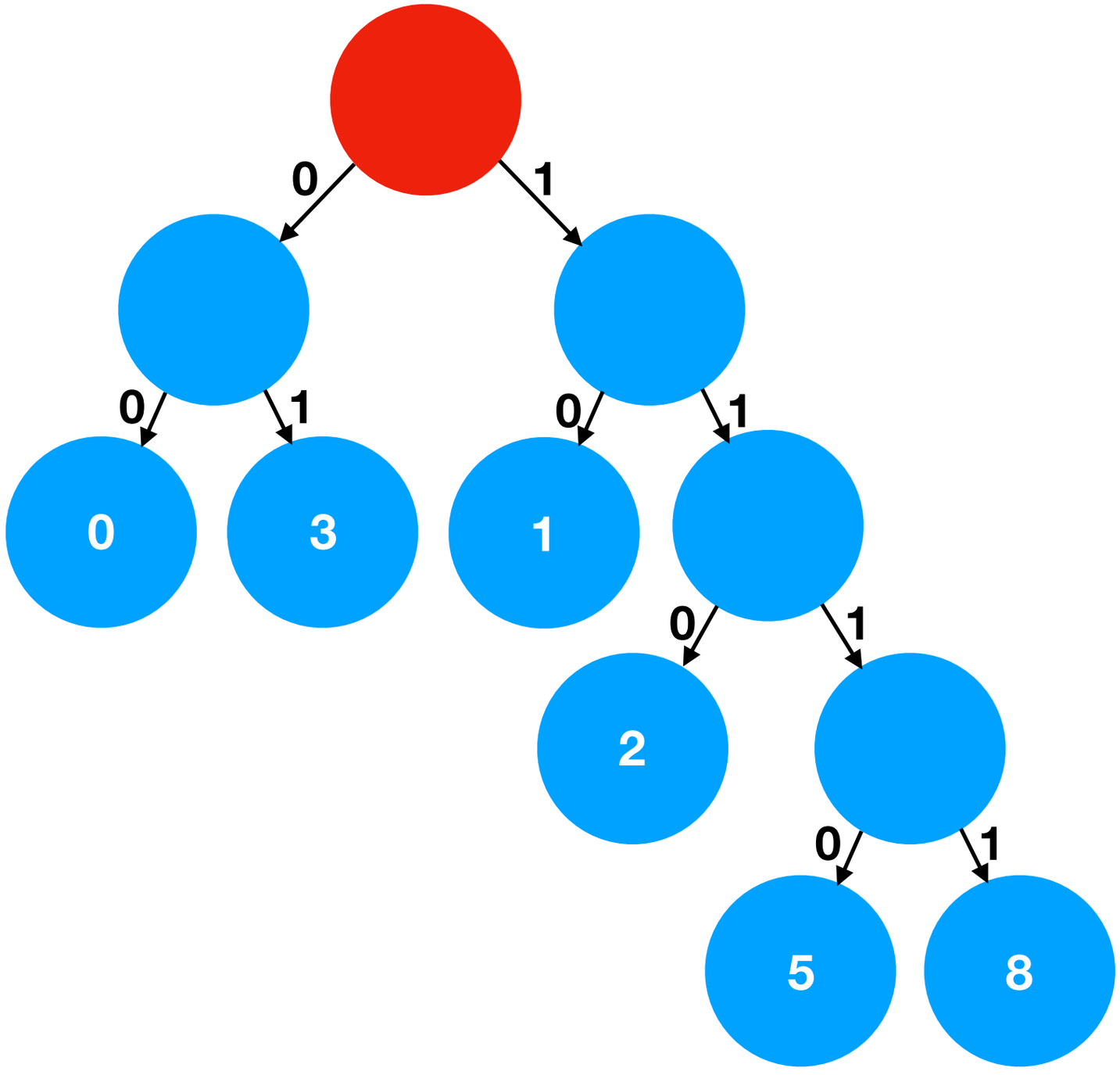

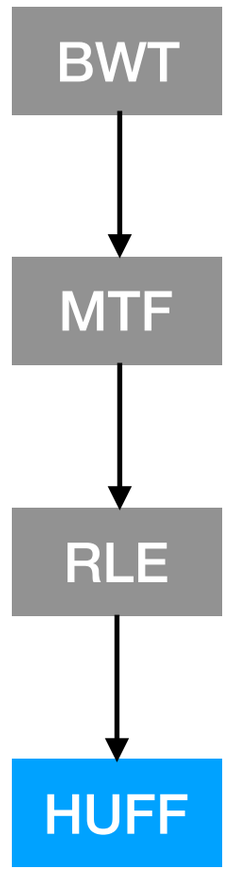

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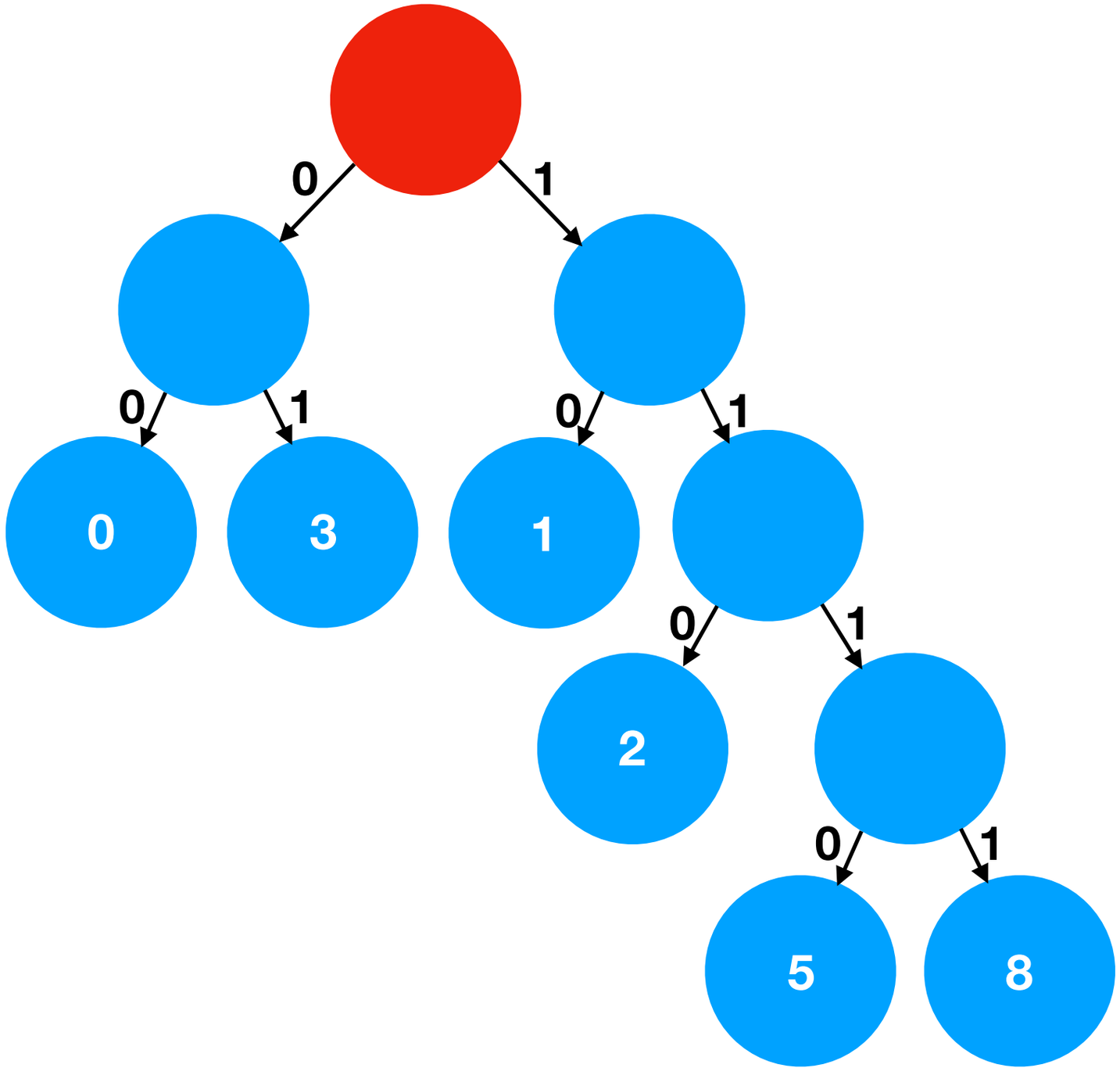

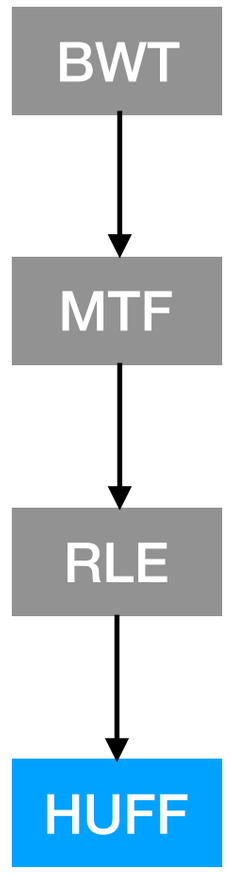

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Zusammenfassung

- Deflate ist ein weit verbreitetes Verfahren um Daten zu komprimieren
- Google macht’s am besten
- Das Kompressionsverfahren bzip2 kombiniert mehrere Teilschritte die in Zusammenarbeit zu Erfolg führen

Vielen Dank für eure Aufmerksamkeit!

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