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Übungsaufgabe 3:

Messreihe 1000 Würfe mit einem 6-seitigen Würfel:

5, 4, 2, 4, 5, 6, 3, 2, 5, 3, 4, 2, 1, 1, 5, 1, 1, 2, 1, 6, 4, 6, 1, 4, 5, 3, 2, 3, 2, 1, 1, 2, 6, 2, 5,
2, 5, 6, 4, 6, 4, 5, 2, 2, 3, 1, 2, 5, 5, 4, 5, 5, 4, 5, 2, 2, 5, 4, 3, 5, 5, 4, 2, 4, 3, 1, 5, 4, 1, 6,
5, 4, 5, 4, 2, 1, 4, 1, 2, 6, 1, 1, 5, 3, 5, 3, 1, 6, 4, 6, 1, 6, 2, 5, 4, 4, 2, 6, 1, 3, 4, 2, 2, 5, 3,
3, 2, 5, 6, 2, 3, 3, 3, 6, 3, 1, 4, 2, 1, 5, 6, 6, 3, 2, 3, 3, 5, 6, 3, 1, 4, 5, 6, 3, 1, 1, 4, 3, 1, 2,
3, 6, 3, 2, 3, 4, 2, 4, 6, 4, 3, 4, 3, 2, 4, 5, 5, 4, 3, 3, 2, 4, 4, 5, 5, 6, 4, 2, 6, 6, 5, 5, 6, 6, 2,
3, 1, 2, 3, 2, 5, 1, 3, 3, 2, 4, 5, 2, 4, 5, 3, 6, 5, 3, 5, 5, 2, 6, 4, 3, 6, 5, 5, 2, 1, 5, 5, 2, 1, 3,
2, 5, 3, 2, 2, 6, 3, 5, 4, 3, 1, 1, 5, 6, 5, 6, 3, 2, 3, 1, 6, 6, 3, 5, 3, 2, 5, 3, 2, 5, 2, 5, 3, 5, 2,
2, 1, 5, 4, 3, 6, 6, 2, 6, 3, 2, 3, 2, 4, 5, 4, 6, 3, 1, 3, 1, 3, 4, 1, 1, 1, 6, 2, 1, 5, 4, 5, 6, 2, 4,
1, 4, 2, 6, 3, 6, 1, 2, 2, 2, 3, 5, 3, 6, 2, 5, 2, 6, 5, 1, 2, 2, 5, 4, 2, 5, 6, 3, 1, 3, 1, 3, 6, 5, 3,
5, 2, 6, 4, 3, 4, 2, 2, 6, 6, 1, 2, 1, 4, 5, 1, 3, 3, 1, 6, 5, 4, 2, 1, 5, 4, 6, 6, 1, 2, 4, 1, 4, 3, 2,
2, 1, 3, 4, 3, 6, 2, 1, 4, 3, 6, 2, 1, 2, 5, 2, 6, 1, 2, 3, 1, 4, 3, 5, 6, 1, 6, 5, 2, 4, 4, 4, 2, 1, 3,
3, 3, 3, 1, 3, 6, 6, 2, 4, 1, 2, 5, 2, 6, 1, 6, 3, 2, 1, 5, 4, 3, 4, 3, 1, 6, 2, 4, 1, 5, 2, 5, 3, 4, 6,
3, 2, 6, 3, 4, 6, 1, 5, 2, 5, 5, 5, 6, 5, 2, 5, 1, 4, 2, 3, 2, 5, 5, 6, 1, 1, 2, 4, 6, 3, 4, 5, 4, 4, 1,
4, 4, 1, 2, 6, 6, 6, 1, 4, 3, 3, 5, 6, 5, 2, 3, 4, 4, 6, 5, 1, 4, 3, 3, 1, 4, 4, 4, 4, 6, 6, 1, 4, 4, 1,
1, 3, 3, 4, 4, 4, 4, 4, 1, 3, 3, 4, 3, 3, 3, 5, 6, 1, 1, 1, 2, 6, 3, 1, 5, 5, 1, 5, 5, 3, 3, 5, 6, 2, 6,
2, 3, 1, 4, 6, 4, 2, 2, 5, 5, 2, 6, 5, 5, 5, 1, 4, 4, 4, 4, 5, 5, 5, 6, 6, 4, 6, 1, 2, 6, 6, 2, 5, 1, 6,
1, 3, 1, 1, 2, 3, 1, 1, 1, 1, 1, 2, 4, 6, 3, 4, 6, 6, 3, 4, 5, 4, 4, 2, 3, 2, 4, 1, 2, 3, 5, 3, 6, 3, 6,
4, 4, 6, 3, 5, 4, 1, 4, 5, 3, 3, 5, 4, 2, 6, 4, 4, 1, 4, 1, 1, 4, 4, 6, 3, 6, 3, 2, 4, 6, 1, 3, 6, 6, 6,
3, 1, 5, 6, 6, 3, 6, 6, 5, 1, 3, 6, 1, 6, 2, 5, 4, 6, 1, 5, 5, 3, 4, 4, 6, 4, 1, 2, 6, 5, 6, 3, 6, 2, 1,
1, 2, 3, 4, 5, 4, 3, 6, 5, 6, 5, 4, 4, 1, 6, 6, 2, 1, 6, 1, 5, 2, 3, 6, 4, 1, 5, 5, 2, 2, 2, 3, 3, 4, 6,
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5, 1, 1, 5, 4, 2, 2, 2, 5, 3, 6, 6, 3, 5, 4, 4, 1, 2, 4, 5, 6, 4, 5, 1, 6, 2, 2, 2, 5, 5, 2, 3, 6, 5, 6,
6, 2, 2, 1, 1, 5, 6, 4, 3, 2, 2, 3, 2, 5, 1, 1, 2, 5, 1, 4, 6, 2, 1, 2, 2, 4, 4, 1, 6, 2, 6, 3, 5, 3, 1,
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5, 6, 3, 1, 5, 3, 2, 6, 5, 6, 4, 3, 1, 1, 1, 3, 4, 2, 3, 4, 1, 5, 4, 3, 1, 5, 6, 4, 3, 6, 5, 2, 1, 2, 5,

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2, 1, 2, 2, 2, 2, 5, 4, 2, 2, 3, 3, 5, 4, 3, 2, 3, 1, 4, 4, 6, 3, 5, 1, 1, 2, 6, 3, 2, 4, 5, 1, 5, 4, 5, 5, 4, 1, 1, 5, 6, 6, 5, 6, 5, 5, 2, 5, 1, 1, 1, 2, 5, 5, 5, 1, 5, 6, 2, 4, 5, 5, 6, 6, 6, 3, 2, 2, 4, 2, 5, 5, 4, 4, 5, 4, 2, 5, 1, 1, 6, 1, 4, 6, 6, 1, 4, 6, 2, 4, 5, 6, 3, 6, 3, 4, 2, 4, 4, 2, 6, 5, 5, 1, 2, 5, 6, 1, 5, 3, 2, 5, 3, 6, 2, 2, 4, 1, 4, 4, 5, 4, 3, 1, 6

Häufigkeiten:

Augenzahl	Anzahl der Würfe	relative Häufigkeit
1	164	0.164
2	177	0.177
3	158	0.158
4	164	0.164
5	175	0.175
6	162	0.162

Berechnung des Medians:

$0.164 + 0.177 + 0.158 = 0.499 \leq 0.5$

$0.164 + 0.177 + 0.158 + 0.164 = 0.663 > 0.5$

Der Median ist also 3 (der dritte Summand stellt Augenzahl 3 da).

Modalwert:

$0.177 > 0.175 > 0.164 > 0.162 > 0.158$

Der Modalwert ist also 2.

Mittwelwert:

$m_1 = \sum_{i=0}^{n-1} x_i p_i$

$m_1 = 1 * 0.164 + 2 * 0.177 + 3 * 0.158 + 4 * 0.164 + 5 * 0.175 + 6 * 0.162 \approx 3.5$

Standardabweichung:

$s = \sqrt{\sum_{i=0}^{n-1} (x_i - m_1)^2 p_i}$

$s = \sqrt{(1 - 3.495)^2 * 0.164 + (2 - 3.495)^2 * 0.177 + (3 - 3.495)^2 * 0.158}$
$\overline{+(4 - 3.495)^2 * 0.164 + (5 - 3.495)^2 * 0.175 + (6 - 3.495)^2 * 0.162} \approx 1.7$

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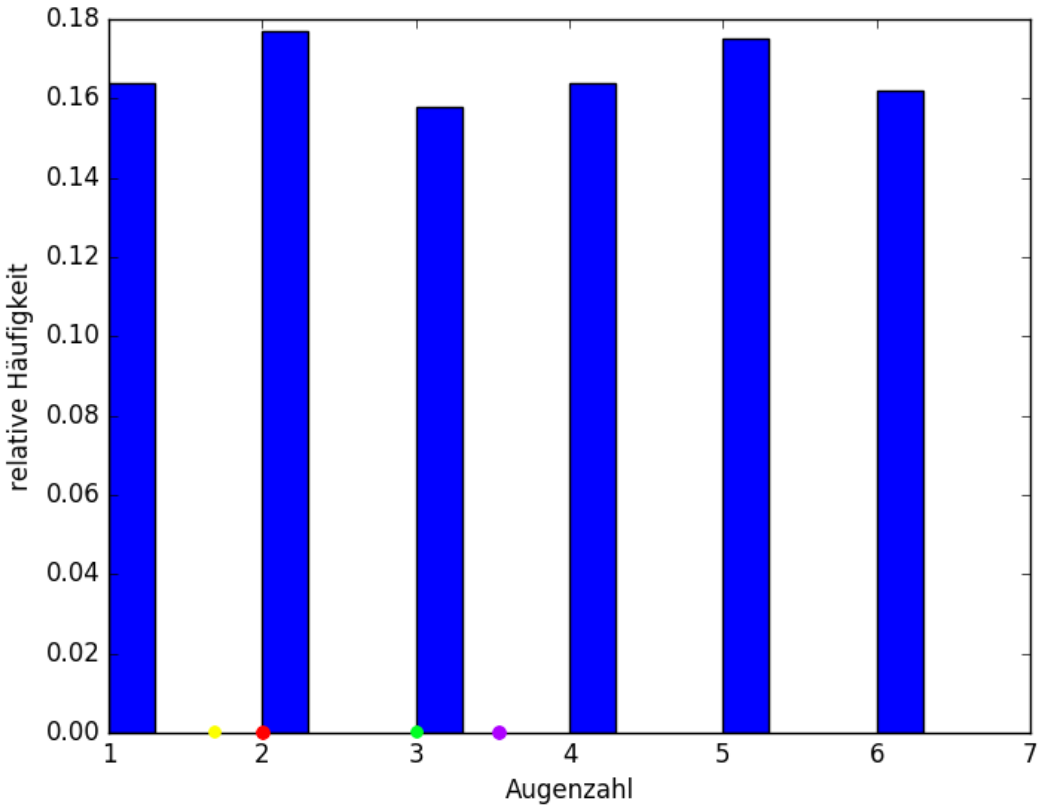

Abbildung 1: Histogramm für 1000 Würfe mit einem 6-seitigen Würfel.

gelb: Standardabweichung, rot: Modalwert, grün: Median, violett: Mittwelwert

Entropie:

$H = \sum_{i=0}^{n-1} p_i log_2(\frac{1}{p_i})$

$H = 0.164 * log_2(\frac{1}{0.164}) + 0.177 * log_2(\frac{1}{0.177}) + 0.158 * log_2(\frac{1}{0.158}) + 0.164 * log_2(\frac{1}{0.164}) + 0.175 * log_2(\frac{1}{0.175}) + 0.162 * log_2(\frac{1}{0.162}) \approx 2.58373$

Max. Entropie:

$H_{max} = log_2(n)$

$H_{max} = log_2(6) \approx 2.58496$

Redundanz:

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$R = H_{max} - H = 2.58496 - 2.58373 \approx 0.001$

Die Redundanz ist sehr klein.

Übungsaufgabe 4:

Messreihe Summe der Augenzahlen bei 1000 Würfe mit zwei Würfeln:

9, 9, 9, 7, 7, 6, 5, 8, 7, 8, 10, 8, 7, 2, 4, 11, 6, 7, 7, 4, 6, 8, 7, 6, 12, 6, 4, 5, 7, 3, 5, 8, 6, 8, 7, 6, 6, 9, 3, 8, 7, 6, 6, 10, 11, 12, 4, 7, 7, 8, 9, 4, 5, 10, 3, 11, 8, 8, 7, 9, 8, 7, 11, 2, 8, 5, 8, 6, 9, 11, 8, 9, 11, 8, 6, 8, 5, 8, 5, 11, 4, 7, 7, 3, 3, 10, 10, 7, 8, 5, 8, 6, 8, 3, 12, 5, 7, 4, 5, 9, 8, 6, 7, 11, 7, 7, 3, 9, 12, 5, 9, 6, 5, 8, 3, 10, 7, 11, 7, 4, 11, 3, 9, 4, 7,10, 2, 11, 4, 5, 10, 7, 3, 7, 7, 10, 11, 7, 4, 7, 3, 9, 6, 7, 8, 6, 7, 6, 8, 7, 10, 6, 4, 8, 9, 6, 7, 11, 11, 9, 8, 6, 6, 11, 9, 9, 4, 8, 5, 4, 4, 4, 7, 7, 8, 10, 5, 7, 9, 9, 7, 5, 8, 5, 8, 8, 3, 7, 5, 7, 4, 7, 8, 8, 5, 6, 4, 5, 10, 9, 4, 5, 3, 6, 5, 7, 7, 11, 5, 7, 8, 8, 5, 5, 6, 7, 6, 6, 7, 5, 9, 11, 8, 6, 6, 11, 8, 5, 8, 6, 3, 5, 3, 3, 10, 11, 8, 5, 12, 9, 11, 7, 10, 9, 7, 6, 11, 9, 7, 3, 8, 7, 2, 6, 6, 7, 4, 10, 5, 8, 7, 6, 4, 6, 9, 4, 9, 6, 10, 4, 5, 10, 11, 8, 4, 6, 10, 5, 3, 7, 8, 2, 8, 9, 6, 5, 11, 6, 5, 11, 7, 8, 6, 12, 6, 6, 10, 4, 6, 9, 10, 6, 4, 7, 7, 8, 10, 10, 4, 3, 9, 9, 9, 3, 12, 4, 12, 8, 9, 12, 10, 11, 3, 8, 8, 5, 6, 8, 10, 7, 3, 11, 5, 7, 8, 5, 5, 6, 6, 7, 7, 10, 6, 8, 4, 4, 8, 12, 5, 7, 5, 6, 4, 7, 3, 9, 3, 11, 7, 8, 4, 7, 7, 4, 5, 9, 8, 8, 2, 6, 5, 4, 6, 5, 5,8, 9, 8, 11, 5, 9, 5, 8, 6, 8, 7, 3, 8, 7, 6, 6, 7, 4, 8, 7, 8, 10, 5, 5, 7, 8, 6, 4, 6, 8, 6, 6, 9, 7, 9, 5, 11, 10, 5, 7, 9, 8, 6, 12, 6, 10, 9, 3, 4, 5, 7, 7, 7, 4, 5, 7, 3, 9, 6, 6, 8, 11, 7, 8, 7, 7, 4, 2, 9, 5, 4, 6, 5, 4, 6, 4, 5, 5, 8, 11, 4, 9, 4, 5, 9, 8, 7, 6, 12, 8, 6, 9, 3, 8, 7, 6, 5, 7, 8, 5, 6, 7, 9, 5, 5, 11, 6, 5, 8, 8, 4, 4, 9, 6, 7, 8, 12, 8, 8, 8, 5, 7, 7, 7, 12, 5, 6, 10, 12, 9, 2, 5, 8, 6, 4, 4, 4, 6, 9, 8, 2, 4, 6, 8, 8, 2, 9, 9, 8, 7, 3, 5, 9, 6, 7, 10, 9, 9, 6, 3, 8, 8, 6, 6, 10, 6, 6, 7, 5, 7, 8, 10, 7, 7, 11, 9, 10, 8, 10, 9, 9, 6, 3, 4, 6, 5, 7, 10, 3, 6, 7,8, 3, 10, 7, 11, 7, 9, 10, 8, 9, 5, 6, 9, 8, 8, 6, 5, 9, 6, 2, 4, 11, 5, 11, 10, 7, 6, 6, 10, 4, 6, 6, 3, 5, 12, 4, 4, 11, 2, 8, 9, 7, 8, 9, 8, 7, 6, 3, 8, 9, 8, 9, 8, 7, 4, 10, 6, 4, 5, 6, 5, 7, 5, 6, 8, 10, 5, 3, 8, 11, 4, 6, 7, 7, 2, 8, 8, 10, 7, 4, 11, 6, 4, 5, 4, 10, 5, 8, 7, 7, 4, 6, 7, 6, 7, 8, 6, 6, 3, 9, 4, 3, 7, 10, 12, 10, 5, 6, 8, 9, 9, 7, 4, 5, 9, 8, 3, 9, 7, 3, 6, 6, 6, 6, 8, 7,2, 12, 6, 5, 7, 8, 8, 10, 7, 5, 6, 8, 5, 3, 10, 7, 6, 8, 11, 9, 10, 8, 7,

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3, 6, 8, 4, 6, 6, 3, 4, 11, 3, 10, 6, 3, 3, 12, 9, 7, 5, 7, 3, 6, 8, 5, 3, 5, 7, 9, 2, 5, 10, 8, 8, 10, 9, 12, 5, 8, 7, 7, 9, 5, 9, 10, 12, 7, 8, 4, 10, 12, 3, 7, 9, 4, 5, 12, 10, 7, 9, 12, 9, 5, 10, 2, 9, 6, 9, 4, 5, 5, 9, 7, 5, 4, 9, 7, 5, 11, 6, 4, 11, 6, 7, 7, 8, 6, 7, 4, 6, 11, 4, 5, 8, 4, 5, 7, 4, 4, 7, 7, 2, 2, 7, 11, 9, 6, 5, 6, 6, 6, 9, 7, 4, 8, 6, 4, 10, 7, 6, 6, 4, 3, 6, 5, 9, 8, 2, 9, 8, 2, 5, 6, 7, 9, 4, 3, 3, 5, 3, 4, 2, 7, 4, 2, 9, 6, 5, 5, 7, 4, 5, 10, 2, 8, 5, 5, 8, 6, 4, 8, 4, 7, 6, 7, 7, 5, 4, 2, 10, 8, 7, 4, 7, 8, 8, 9, 7, 8, 3, 4, 10, 2, 8, 12, 6, 11, 10, 7, 9, 7, 4, 6, 12, 3, 6, 7, 7, 3, 9, 6, 6, 6, 10, 6, 5, 6, 4, 3, 6, 5, 7, 5, 4, 4, 6, 8, 9, 10, 10, 7, 10, 5, 6, 12, 5, 5, 7, 9, 9, 7,11, 6, 8, 6, 7, 7, 6, 6, 12, 10, 12, 7, 6, 4, 4, 3, 8, 6, 11, 4, 2, 4, 7, 10, 10, 5, 7, 5, 9, 11, 8, 3, 12, 5, 8, 6, 7, 6, 7, 8, 9, 11, 5, 4, 6, 8, 5, 6, 6, 6, 10, 7, 12, 7, 9, 7

Häufigkeiten

Summe der Augenzahlen	Anzahl der Würfe	relative Häufigkeit
2	26	0.026
3	59	0.059
4	97	0.097
5	118	0.118
6	153	0.153
7	162	0.162
8	138	0.138
9	98	0.098
10	68	0.068
11	50	0.05
12	31	0.031

Median: 7

Modalwert: 7

Mittwelwert: 6.847

Standardabweichung: ≈ 2.4

Entropie: ≈ 3.2658

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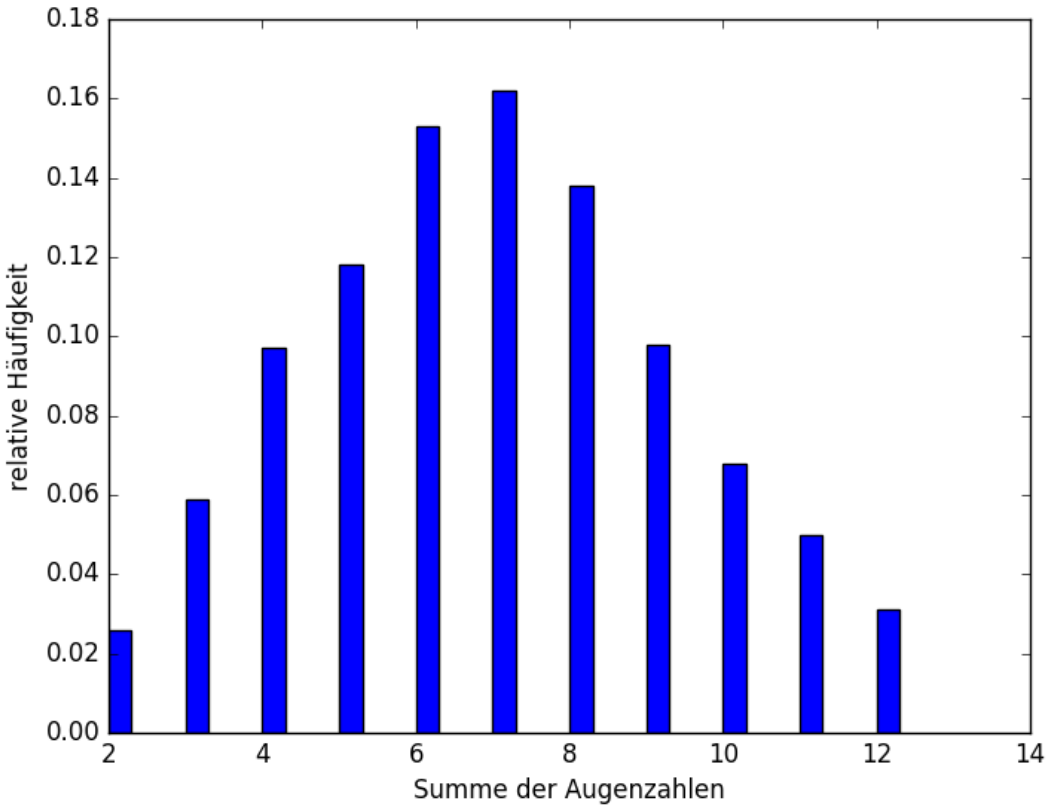

Abbildung 2: Normales Histogramm für die Summe der Augenzahlen mit zwei Würfeln bei 1000 Würfen

Max. Entropie: ≈ 3.4594

Redundanz: ≈ 0.194

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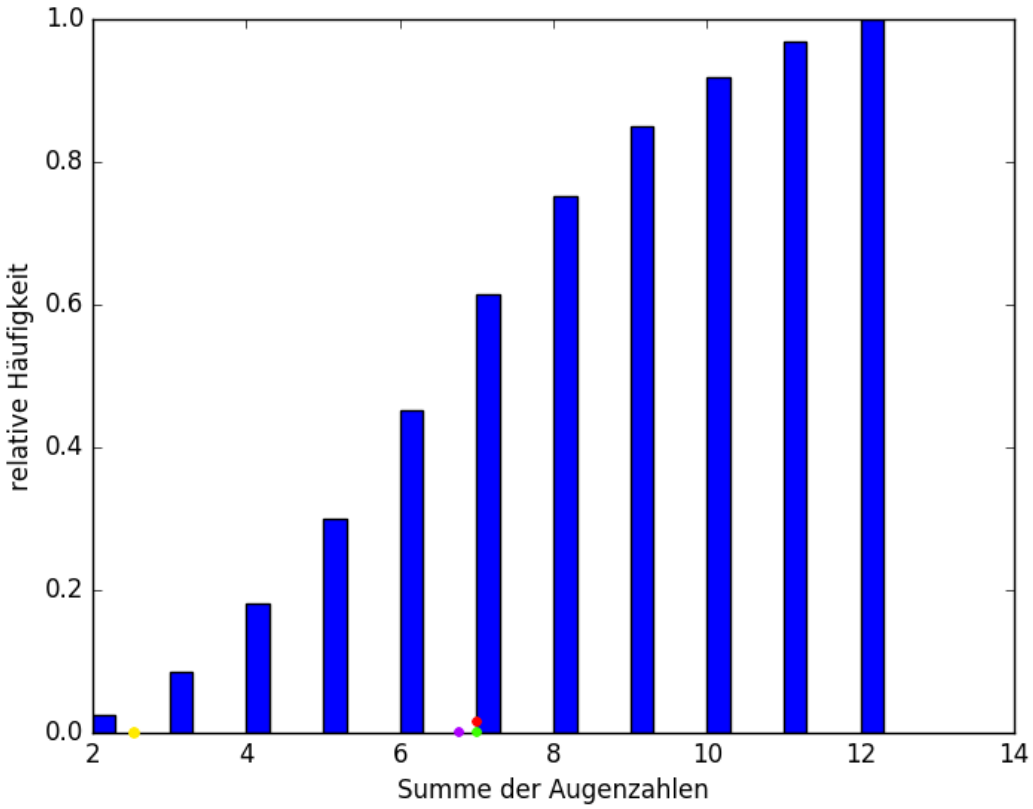

Abbildung 3: Kumulative Histogramm für die Summe der Augenzahlen mit zwei Würfeln bei 1000 Würfen

gelb: Standardabweichung, rot: Modalwert, grün: Median, violett: Mittwelwert