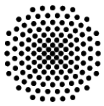

Universität Stuttgart

B-Splines for Sparse Grids: Algorithms and Application to Higher-Dimensional Optimization

Vom Stuttgarter Zentrum für Simulationswissenschaften der Universität Stuttgart zur Erlangung der Würde eines Doktors der Naturwissenschaften (Dr. rer. nat.) genehmigte Abhandlung

Vorgelegt von

Emmett Brown
aus Hill Valley, California

Hauptberichter:	Prof. Dr. Albert Einstein
Mitberichter:	Prof. Dr. Blaise Pascal Prof. Dr. Marie Curie Prof. Dr. Charles Darwin

Tag der mündlichen Prüfung: 21. Oktober 2015

Institute for Advanced Time Travel

2015

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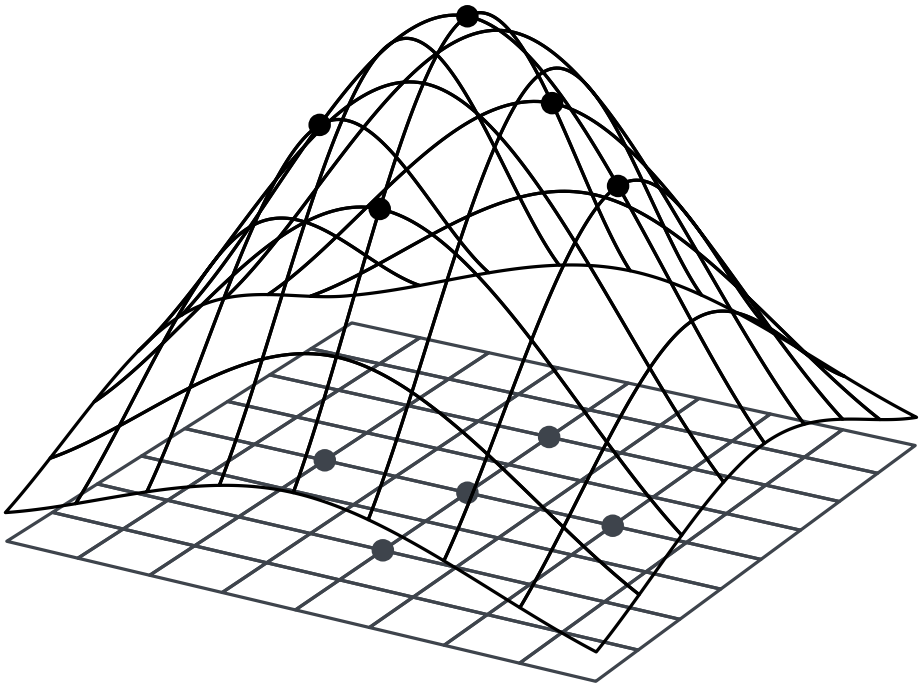
Emmett Brown

INVENTING TIME TRAVEL

Theory and Applications of the Flux Capacitor



University of Stuttgart
Germany

SimTech

IPVS

SGS

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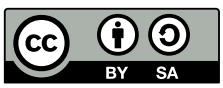
> *It seems that it is not enough to have a good idea or insight. One needs, like Schoenberg, the appreciation and courage to develop the idea systematically, make its objects mathematically presentable by giving them names, and give them much exposure in many papers.*
>
> — Carl de Boor [Boo16]

COVER FIGURE A regular sparse grid in two dimensions *(dots)* as a subset of the full grid *(mesh, bottom)* with a bicubic B-spline *(mesh, top)*.

Compiled as version `v206` on April 2, 2018 at 9:51am.
Committed as `23febca*` on April 2, 2018 at 9:51am.



Although this thesis was written with uttermost care, it cannot be ruled out that it contains errors. Please send any corrections and mistakes to thesis@example.com.

Contents

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Lists of Figures, Tables, Algorithms, and Theorems

List of Figures

List of Tables

List of Algorithms

List of Theorems

Abstract/Kurzzusammenfassung

Abstract

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

Kurzzusammenfassung

TODO: write Dies hier ist ein Blindtext zum Testen von Textausgaben. Wer diesen Text liest, ist selbst schuld. $\sin^2(\alpha) + \cos^2(\beta) = 1$. Der Text gibt lediglich den Grauwert der Schrift an $E = mc^2$. Ist das wirklich so? Ist es gleichgültig, ob ich schreibe: „Dies ist ein Blindtext“ oder „Huardest gefburn“? Kjift – mitnichten! Ein Blindtext bietet mir wichtige Informationen. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. An ihm messe ich die Lesbarkeit einer Schrift, ihre Anmutung, wie harmonisch die Figuren zueinander stehen und prüfe, wie breit oder schmal sie läuft. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. Ein Blindtext sollte möglichst viele verschiedene Buchstaben enthalten und in der Originalsprache gesetzt sein. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$. Er muss keinen Sinn ergeben, sollte aber lesbar sein. $\mathrm{d}\Omega = \sin\vartheta \mathrm{d}\vartheta \mathrm{d}\varphi$. Fremdsprachige Texte wie „Lorem ipsum“ dienen nicht dem eigentlichen Zweck, da sie eine falsche Anmutung vermitteln.

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Preface

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

Stuttgart, October 21, 2015
Emmett Brown

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1 Introduction

> *Ah, Jesus Christ! Jesus Christ, Doc, you disintegrated Einstein!*
>
> — Marty McFly

TODO: write

Citations: [Boo72]

Hello World! `Hello World!`

Now I'm citing all references for demonstration purposes. TODO: don't cite everything

Here are some umlauts: äöüSS

I'm testing the glossary: non-uniform rational B-splines (NURBS) are very cool.

1.1 Bla

This isTODO: write definedTODO: write as $a := 2b$. This is the function f (which is defined as $y =: f(x)$).

Header 1	Header 2	Header 3	Header 4
bla	bla	bla	bla
bla	bla	bla	bla
bla	bla	bla	bla

TABLE 1.1 This is a test table.

$$X \times Y \tag{1.1}$$

$$A \cdot \boldsymbol{x} = \boldsymbol{b} \tag{1.2}$$

$$\min_{\boldsymbol{x} \in [0,1]} \int_{\Omega} f(\boldsymbol{x}, \boldsymbol{y}) d\boldsymbol{y} \tag{1.3}$$

$$4(a+b)f(x)g(x)h(x)p(x)(c+d)fghf'g'h' \tag{1.4}$$

$$f(x)\cos(x)g(x) \tag{1.5}$$

$$\mathrm{f}(x)\cos(x)\mathrm{g}(x) \tag{1.6}$$

Tab. 1.1

Fig. 1.1

Fig. 1.1a

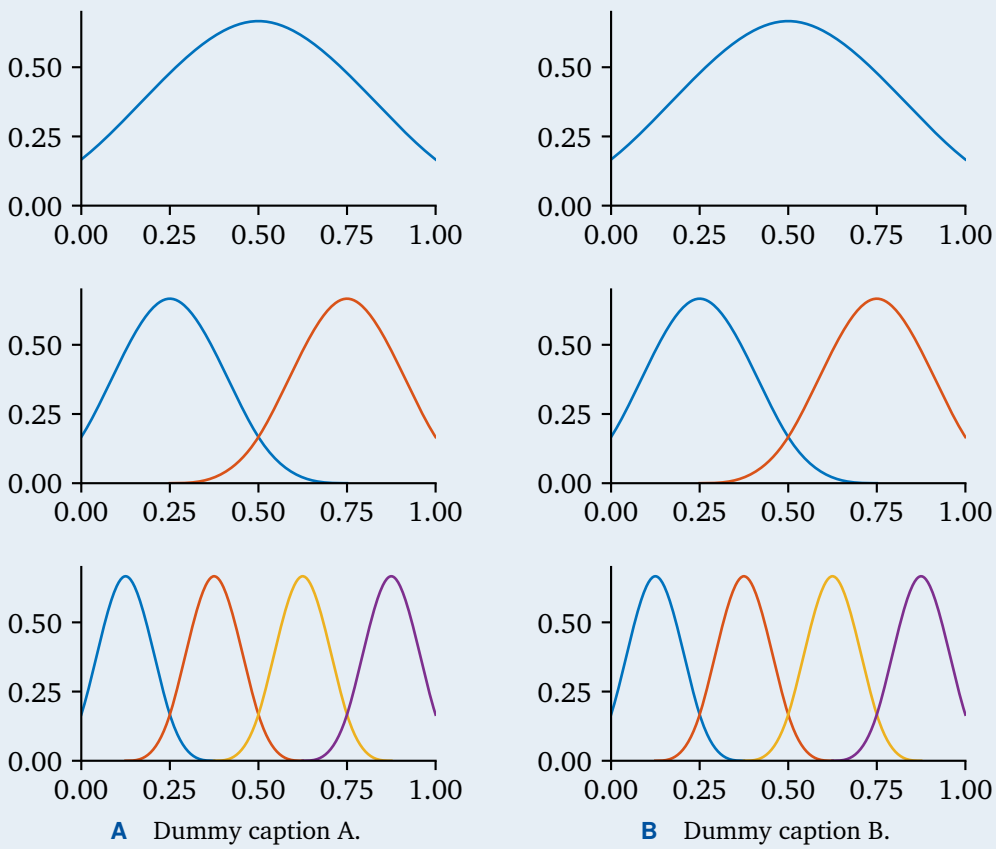
Fig. 1.1b

Fig. 1.2

Alg. 1.1

THEOREM 1.1 (TODO Theorem)

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. *If you read this text, you will get no information* $E = mc^2$. *Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look.* $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. *This text should contain all letters of the alphabet and it should be written in of the original language.* $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. *There is no need for special contents, but the length of words should match the language.* $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.



A Dummy caption A. **B** Dummy caption B.

FIGURE 1.1 This is a test caption.

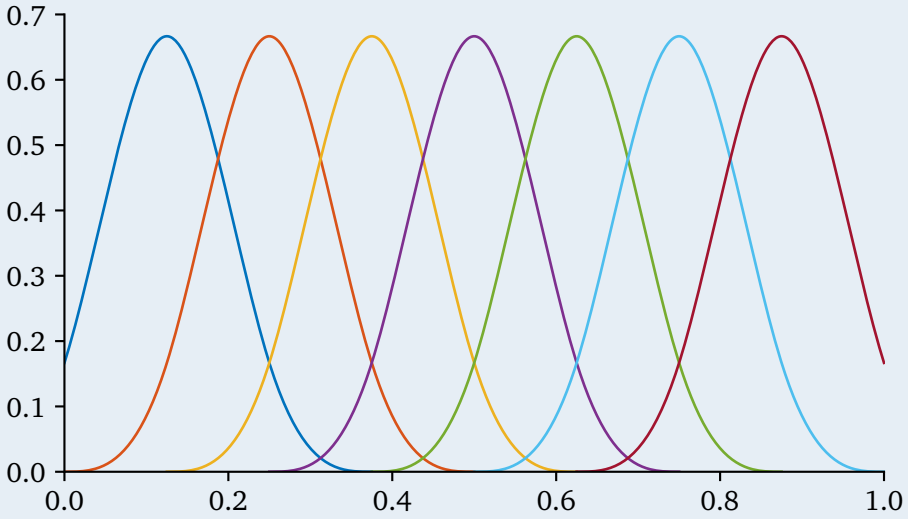


FIGURE 1.2 This is a test caption. This is a test caption. This is a test caption. This is a test caption. This is a test caption. This is a test caption. This is a test caption. This is a test caption. This is a test caption.

```
1  function a = GetAffectedBasisFunctions(X, α, x, t, ℓ, j, b)
2    if x_{ℓ,j} ∉ X then return 0          ⇝ nichts tun, falls Gitterpunkt nicht vorhanden
3    if t = d then
4      a ← α_{ℓ,j} · (b · φ_{ℓ_d,j_d}(x_d))    ⇝ letzte Dimension: Summanden zu Ergebnis addieren
5      if x_{ℓ,j}^{(rn(d))} ∈ X then a ← a + α_{ℓ,j}^{(rn(d))} · (b · φ_{ℓ_d,j_d}^{(rn(d))}(x_d))
6      if x_{ℓ,j}^{(ln(d))} ∈ X then a ← a + α_{ℓ,j}^{(ln(d))} · (b · φ_{ℓ_d,j_d}^{(ln(d))}(x_d))
7    else
8      a ← GABF(X, α, x, t+1, ℓ, j, b · φ_{ℓ_t,j_t}(x_t))          ⇝ nächste Dimension
9      if x_{ℓ,j}^{(rn(t))} ∈ X then a ← a+GABF(X, α, x, t+1, ℓ, j^{(rn(t))}, b · φ_{ℓ_t,j_t}^{(rn(t))}(x_t))
10     if x_{ℓ,j}^{(ln(t))} ∈ X then a ← a+GABF(X, α, x, t+1, ℓ, j^{(ln(t))}, b · φ_{ℓ_t,j_t}^{(ln(t))}(x_t))
11   if x_t > j_t h_{ℓ_t} then a ← a + GABF(X, α, x, t, ℓ^{(rc(t))}, j^{(rc(t))}, b)          ⇝
   nächster Level
12   else a ← a + GABF(X, α, x, t, ℓ^{(lc(t))}, j^{(lc(t))}, b)
13   return a
```

ALGORITHM 1.1 Approximative Auswertung von Linearkombinationen auf dünnen Gittern, Zeilen 5, 6, 9, 10 nicht für stückweise lineare Basisfunktionen,
input: Gitter $X = \{\boldsymbol{x}_i\}_i$, Koeffizienten $\boldsymbol{\alpha} = (\alpha_i)_i$, Auswertungspunkt $\boldsymbol{x} \in [0,1]^d$, aktuelle Dimension $t \in \{1,\dots,d\}$ (anfangs 1), Level und Index $(\boldsymbol{\ell}, \boldsymbol{j})$ des aktuellen Punkts (für randlose Gitter anfangs $(\boldsymbol{e}, \boldsymbol{e})$) und aktuelles Produkt b von 1D-Auswertungen (anfangs 1),
output: $a \approx \widetilde{f}(\boldsymbol{x}) = \sum_{k=1}^{N} \alpha_k \varphi_k(\boldsymbol{x})$ (für stückweise lineare Funktionen sogar $a = \widetilde{f}(\boldsymbol{x})$)

LEMMA 1.2 (TODO Lemma)
TODO

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

DEFINITION 1.3 (TODO Definition)
TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text,

you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

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$$\bar{x} = \frac{1}{n}\sum_{i=1}^{i=n} x_i = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

$$\int_0^\infty e^{-\alpha x^2} \mathrm{d}x = \frac{1}{2}\sqrt{\int_{-\infty}^{\infty} e^{-\alpha x^2} \mathrm{d}x \int_{-\infty}^{\infty} e^{-\alpha y^2} \mathrm{d}y} = \frac{1}{2}\sqrt{\frac{\pi}{\alpha}}$$

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$$\sum_{k=0}^{\infty} a_0 q^k = \lim_{n\to\infty} \sum_{k=0}^{n} a_0 q^k = \lim_{n\to\infty} a_0 \frac{1-q^{n+1}}{1-q} = \frac{a_0}{1-q}$$

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-p \pm \sqrt{p^2 - 4q}}{2}$$

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

$$\frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} + \frac{\partial^2 \Phi}{\partial z^2} = \frac{1}{c^2} \frac{\partial^2 \Phi}{\partial t^2}$$

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

2 The Flux Capacitor

> *If my calculations are correct, when this baby hits 88 miles per hour. . . you're gonna see some serious shit.*
>
> — Emmett Brown

TODO: write

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

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3 Conclusion

TODO: write Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. $\sin^2(\alpha) + \cos^2(\beta) = 1$. If you read this text, you will get no information $E = mc^2$. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. $\sqrt[n]{a} \cdot \sqrt[n]{b} = \sqrt[n]{ab}$. This text should contain all letters of the alphabet and it should be written in of the original language. $\frac{\sqrt[n]{a}}{\sqrt[n]{b}} = \sqrt[n]{\frac{a}{b}}$. There is no need for special contents, but the length of words should match the language. $a\sqrt[n]{b} = \sqrt[n]{a^n b}$.

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A Proofs

This is an appendix chapter.

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B Bibliography

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All URLs have last been checked on October 21, 2015.

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