

Mathematics Notebook

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Contents

| I | Reference |
|----------|---|
| 1 | Numbers 9 |
| 1.1 | Number Systems 9 |
| 1.2 | Prime Numbers 9 |
| 1.2.1 | Listing of Prime Numbers 2-997 |
| 10 | |
| 2 | Operations 11 |
| 2.1 | Dyadic Operations 11 |
| 3 | Notation 13 |
| 3.1 | Negation Notation 13 |
| 3.2 | Multiplication Notation 13 |
| 3.3 | Power Notation 14 |
| 3.4 | Logarithm Notation 14 |
| 3.5 | Derivative Notation 14 |
| 4 | Properties 17 |
| 4.1 | Summary of Field Properties 17 |
| 4.2 | Properties of Addition 17 |
| 4.3 | Properties of Multiplication 18 |
| 4.4 | Properties of Subtraction 19 |
| 4.5 | Properties of Powers 19 |
| 4.6 | Properties of Equality 19 |
| 4.7 | Properties of Inequality 20 |
| 5 | Identities 21 |
| 5.1 | Power Identities 21 |
| 5.2 | Logarithm Identities 22 |
| 5.3 | Trigonometric Identities 22 |
| 6 | Limit Properties 27 |
| 6.1 | Algebraic Limit Theorem 27 |

| | | |
|----------|--------------------------------|-----------|
| 7 | Calculus Rules | 29 |
| 7.1 | Monomial Derivative Rules | 29 |
| 7.2 | Derivative Structural Rules | 29 |
| 7.3 | Trigonometric Derivative Rules | 30 |
| 7.4 | Logarithm Derivative Rules | 31 |
| 7.5 | Exponential Derivative Rules | 31 |

II

Algebra

| | | |
|-----------|---|-----------|
| 8 | Simplifying Univariate Polynomials | 35 |
| 8.1 | Simplifying Degree 0 Univariate Monomials | 35 |
| 8.2 | Simplifying Degree 1 Univariate Monomials | 37 |
| 8.3 | Simplifying Degree 2 Univariate Monomials | 43 |
| 8.4 | Simplifying Degree 3 Univariate Monomials | 46 |
| 8.5 | Simplifying Degree 1 Univariate Binomials | 46 |
| 8.6 | Simplifying Degree 2 Univariate Binomials | 53 |
| 8.7 | Simplifying Degree 2 Univariate Trinomials | 55 |
| 8.8 | Simplifying Degree n Univariate Polynomials | 59 |
| 9 | Simplifying Multivariate Monomials | 61 |
| 9.1 | Simplifying Degree -1 Multivariate Monomials | 61 |
| 9.2 | Simplifying Degree 2 Multivariate Monomials | 61 |
| 9.3 | Simplifying Degree 2 Multivariate Binomials | 62 |
| 9.4 | Simplifying Degree 2 Multivariate Trinomials | 62 |
| 10 | Factoring Univariate Trinomials | 65 |
| 11 | Solving Linear Equations | 67 |
| 11.1 | Power Inverse | 67 |
| 12 | Solving Quadratic Equations | 73 |
| 12.1 | Multiplicative Inverse | 73 |
| 12.2 | Completing The Square | 74 |

III

Functions

| | | |
|-----------|-------------------|-----------|
| 13 | Functions | 83 |
| 13.1 | Inverse Functions | 84 |
| 13.2 | Inverses | 84 |

| | | |
|-----------|---|-----|
| 14 | Derivative by First Principles | 87 |
| 14.1 | Limit of the Difference Quotient | 87 |
| 15 | Derivative Rules | 89 |
| 15.1 | Derivative of a Monomial Functions | 89 |
| 15.2 | Derivative of Polynomial Functions | 90 |
| 15.3 | Derivative of a Quotient | 96 |
| 15.4 | Derivative of a Rational Function | 97 |
| 16 | Equations of Tangent & Secant Lines | 99 |
| 16.1 | Essential Questions | 99 |
| 16.2 | Finding the Equation of the Tangent Line | 99 |
| 17 | First Derivative Test | 103 |
| 18 | Curve Sketching | 105 |
| 18.0.1 | Finding the vertex of a quadratic function using differentiation. | 105 |
| 19 | Second Derivative Test | 107 |
| 20 | Curve Sketching | 109 |
| | Bibliography | 111 |
| | Bibliography | 111 |
| | Websites | 111 |
| | Articles | 111 |
| | Index | 113 |

Reference

| | | |
|----------|--------------------------------|----|
| 1 | Numbers | 9 |
| 1.1 | Number Systems | |
| 1.2 | Prime Numbers | |
| 2 | Operations | 11 |
| 2.1 | Dyadic Operations | |
| 3 | Notation | 13 |
| 3.1 | Negation Notation | |
| 3.2 | Multiplication Notation | |
| 3.3 | Power Notation | |
| 3.4 | Logarithm Notation | |
| 3.5 | Derivative Notation | |
| 4 | Properties | 17 |
| 4.1 | Summary of Field Properties | |
| 4.2 | Properties of Addition | |
| 4.3 | Properties of Multiplication | |
| 4.4 | Properties of Subtraction | |
| 4.5 | Properties of Powers | |
| 4.6 | Properties of Equality | |
| 4.7 | Properties of Inequality | |
| 5 | Identities | 21 |
| 5.1 | Power Identities | |
| 5.2 | Logarithm Identities | |
| 5.3 | Trigonometric Identities | |
| 6 | Limit Properties | 27 |
| 6.1 | Algebraic Limit Theorem | |
| 7 | Calculus Rules | 29 |
| 7.1 | Monomial Derivative Rules | |
| 7.2 | Derivative Structural Rules | |
| 7.3 | Trigonometric Derivative Rules | |
| 7.4 | Logarithm Derivative Rules | |
| 7.5 | Exponential Derivative Rules | |

1. Numbers

1.1 Number Systems

Definition 1.1.1 – Natural Numbers.

$$\mathbb{N} = \{0, 1, 2, 3, \dots\}$$

-  It is not uncommon for zero to be excluded from the natural numbers. In fact, some exclude zero from the natural numbers and then describe the set of natural numbers that include zero the whole numbers.

$$\mathbb{W} = \{0, 1, 2, 3, \dots\}$$

For the purposes of these notes, zero will be included within the set of natural numbers.

Definition 1.1.2 – Integers.

$$\mathbb{Z} = \{\dots, -3, -2, -1, 0, 1, 2, 3, \dots\}$$

Definition 1.1.3 – Positive Integers.

$$\mathbb{Z}^+ = \{1, 2, 3, \dots\}$$

Definition 1.1.4 – Rational Numbers.

$$\mathbb{Q} = \{m/n \mid m, n \in \mathbb{Z}, n \neq 0\}$$

Definition 1.1.5 – Proper Fraction. Given $m < n$, then the fraction m/n is called **proper**.

Definition 1.1.6 – Improper Fraction. Given $m > n$, then the fraction m/n is called **improper**.

1.2 Prime Numbers

Definition 1.2.1 – Greatest Common Divisor. Suppose that m and n are positive integers. The greatest common divisor is the largest divisor (factor) common to both m and n .

Definition 1.2.2 – Relatively Prime. Two integers m and n are relatively prime to each other, $m \perp n$, if they share no common positive integer divisors (factors) except 1.

$$m \perp n \text{ if } \gcd(m, n) = 1.$$

1.2.1 Listing of Prime Numbers 2-997

| | | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2 | 3 | 5 | 7 | 11 | 13 | 17 | 19 | 23 | 29 | 31 | 37 |
| 41 | 43 | 47 | 53 | 59 | 61 | 67 | 71 | 73 | 79 | 83 | 89 |
| 97 | 101 | 103 | 107 | 109 | 113 | 127 | 131 | 137 | 139 | 149 | 151 |
| 157 | 163 | 167 | 173 | 179 | 181 | 191 | 193 | 197 | 199 | 211 | 223 |
| 227 | 229 | 233 | 239 | 241 | 251 | 257 | 263 | 269 | 271 | 277 | 281 |
| 283 | 293 | 307 | 311 | 313 | 317 | 331 | 337 | 347 | 349 | 353 | 359 |
| 367 | 373 | 379 | 383 | 389 | 397 | 401 | 409 | 419 | 421 | 431 | 433 |
| 439 | 443 | 449 | 457 | 461 | 463 | 467 | 479 | 487 | 491 | 499 | 503 |
| 509 | 521 | 523 | 541 | 547 | 557 | 563 | 569 | 571 | 577 | 587 | 593 |
| 599 | 601 | 607 | 613 | 617 | 619 | 631 | 641 | 643 | 647 | 653 | 659 |
| 661 | 673 | 677 | 683 | 691 | 701 | 709 | 719 | 727 | 733 | 739 | 743 |
| 751 | 757 | 761 | 769 | 773 | 787 | 797 | 809 | 811 | 821 | 823 | 827 |
| 829 | 839 | 853 | 857 | 859 | 863 | 877 | 881 | 883 | 887 | 907 | 911 |
| 919 | 929 | 937 | 941 | 947 | 953 | 967 | 971 | 977 | 983 | 991 | 997 |

2. Operations

2.1 Dyadic Operations

Definition 2.1.1 – Operation of Addition (OOA).

$$\underbrace{\begin{array}{c} a \\ \text{Augend} \end{array}}_{\text{Sum}} + \underbrace{\begin{array}{c} b \\ \text{Addend} \end{array}}_{\text{Sum}} \quad (2.1)$$

More generally,

$$\underbrace{\begin{array}{c} a \\ \text{Summand} \end{array}}_{\text{Sum}} + \underbrace{\begin{array}{c} b \\ \text{Summand} \end{array}}_{\text{Sum}} \quad (2.2)$$

Definition 2.1.2 – Operation of Multiplication (OOM).

$$\underbrace{\begin{array}{c} a \\ \text{Multiplicand} \end{array}}_{\text{Product}} \times \underbrace{\begin{array}{c} b \\ \text{Multiplier} \end{array}}_{\text{Product}} \quad (2.3)$$

More generally,

$$\underbrace{\begin{array}{c} a \\ \text{Factor} \end{array}}_{\text{Product}} \times \underbrace{\begin{array}{c} b \\ \text{Factor} \end{array}}_{\text{Product}} \quad (2.4)$$

Definition 2.1.3 – Operation of Exponentiation (OOE).

$$\underbrace{\begin{array}{c} b \\ \text{base} \end{array}}_{\text{Power}}^m \quad (2.5)$$

Definition 2.1.4 – Common Denominator (CD).

$$\frac{a}{b} + \frac{c}{b} = \frac{a+c}{b} \quad (2.6a)$$

$$\frac{a+c}{b} = \frac{a}{b} + \frac{c}{b} \quad (2.6b)$$

Rule 2.1.1 – Fraction Operation of Addition (FOOA).

$$\frac{a}{b} + \frac{c}{d} = \frac{ad + bc}{bd} \quad (2.7a)$$

$$\frac{ad + bc}{bd} = \frac{a}{b} + \frac{c}{d} \quad (2.7b)$$

3. Notation

3.1 Negation Notation

Notation 3.1.1 – Operation of Negation (ONeg).

$$\neg a = \neg a \quad (3.1a)$$

$$\neg a = -a \quad (3.1b)$$

I have used a different symbol, \neg , as the prefix negation operator only to differentiate it from the minus sign infix operator symbol, $-$, which is also used as the infix operator for the dyadic operation of subtraction. I will refer to this change of symbol as ONeg. This is used only as a teaching tool and should not be confused with the logic negation operator. Another advantage of using this symbol is that it reduces the number of delimiters used in an expression for example, $\neg a$ versus $(-a)$.

- Negative five: -5
- Negative five: $\neg 5$
- Four minus five: $4 - 5$
- Four minus negative five: $4 - \neg 5$
- Four minus negative five: $4 - (-5)$
- Four minus negative five: $4 - \neg 5$
- Negative four minus five: $-4 - 5$
- Negative four minus five: $\neg 4 - 5$

3.2 Multiplication Notation

Notation 3.2.1 – Multiplication Center-Dot (MC).

$$a \cdot b \quad (3.2)$$

Notation 3.2.2 – Multiplication Juxtaposition (MJ).

$$ab, a(b), (a)b, (a)(b), a[b], [a]b, [a][b] \quad (3.3)$$

Notation 3.2.3 – Multiplication Times (MT).

$$a \times b \quad (3.4)$$

Notation 3.2.4 – Juxtaposition to Center-Dot (JTC).

$$ab = a \cdot b \quad (3.5)$$

Notation 3.2.5 – Center-Dot to Justaposition (CTJ).

$$a \cdot b = ab \quad (3.6)$$

3.3 Power Notation

Notation 3.3.1 – Power Exponent Negative Exponent (PoNegE).

$$b^{-k} = \frac{1}{b^k} \quad (3.7)$$

$$\frac{1}{b^k} = b^{-k} \quad (3.8)$$

Notation 3.3.2 – Power To Factor (PoTF).

$$a^n = a_1 \cdot a_2 \cdot \dots \cdot a_{n-1} \cdot a_n \quad (3.9)$$

Notation 3.3.3 – Power To Logarithm (PoTL).

$$y = b^x \Rightarrow x = \log_b y \quad (3.10)$$

Notation 3.3.4 – Factor To Power (FTPo).

$$a_1 \cdot a_2 \cdot \dots \cdot a_{n-1} \cdot a_n = a^n \quad (3.11)$$

Notation 3.3.5 – Radical To Power (RTPo).

$$\sqrt[m]{b^n} = b^{\frac{n}{m}} \quad (3.12)$$

3.4 Logarithm Notation

Notation 3.4.1 – Logarithm Exponent Visible (LEV).

$$\log_b y \Rightarrow \log_b y = x \quad (3.13)$$

Notation 3.4.2 – Logarithm to Power (LTPo).

$$x = \log_b y \Rightarrow y = b^x \quad (3.14)$$

3.5 Derivative Notation

Notation 3.5.1 – Leibniz's first derivative.

$$\frac{dy}{dx} = \frac{d[f(x)]}{dx} = \frac{d}{dx}[f(x)] \quad (3.15)$$

Notation 3.5.2 – Leibniz's second derivative.

$$\frac{d^2y}{dx^2} \quad (3.16)$$

Notation 3.5.3 – Leibniz's nth derivative.

$$\frac{d^n y}{dx^n} \quad (3.17)$$

Notation 3.5.4 – Leibniz's Evaluate derivative.

$$\left. \frac{dy}{dx} \right|_{x=a} = \frac{dy}{dx}(a) \quad (3.18)$$

Notation 3.5.5 – LaGrange's first derivative.

$$f'(x) \quad (3.19)$$

Notation 3.5.6 – LaGrange's second derivative.

$$f''(x) \quad (3.20)$$

Notation 3.5.7 – LaGrange's nth derivative.

$$f^{(n)}(x) \quad (3.21)$$

Notation 3.5.8 – LaGrange's Evaluate derivative.

$$f'(a) \quad (3.22)$$

Notation 3.5.9 – Euler's first derivative.

$$Df = D_x f \quad (3.23)$$

Notation 3.5.10 – Euler's second derivative.

$$D^2 f = D_x^2 f \quad (3.24)$$

Notation 3.5.11 – Euler's nth derivative.

$$D^n f = D_x^n \quad (3.25)$$

4. Properties

4.1 Summary of Field Properties

| Name | Addition | Multiplication |
|--------------|---------------------------------------|---|
| Commutative | $a + b = b + a$ | $a \cdot b = b \cdot a$ |
| Associative | $(a + b) + c = a + (b + c)$ | $(a \cdot b) \cdot c = a \cdot (b \cdot c)$ |
| Distributive | $a(b + c) = ab + ac$ | $(a + b)c = ac + bc$ |
| Identity | $a + \mathbf{0} = a = \mathbf{0} + a$ | $a \cdot \mathbf{1} = a = \mathbf{1} \cdot a$ |
| Inverse | $a + (-a) = 0 = (-a) + a$ | $a \cdot a^{-1} = 1 = a^{-1} \cdot a$ |

Table 4.1: Summary of the Field Properties

4.2 Properties of Addition

Property 4.2.1 – Commutative Property of Addition (CPA).

$$ab = ba \quad (4.1)$$

Property 4.2.2 – Associative Property of Addition (APA).

$$a + b + c = (a + b) + c \quad (4.2a)$$

$$a + b + c = a + (b + c) \quad (4.2b)$$

Property 4.2.3 – Distributive Property Factoring (DPF).

$$ba + ca = (b + c)a \quad (4.3a)$$

$$ab + ac = a(b + c) \quad (4.3b)$$

Property 4.2.4 – Additive Identity (AId).

$$a = a + \mathbf{0} \quad (4.4a)$$

$$a + \mathbf{0} = a \quad (4.4b)$$

Property 4.2.5 – Additive Inverse (AI).

$$a + (-a) = 0 \quad (4.5a)$$

4.3 Properties of Multiplication

Property 4.3.1 – Commutative Property of Multiplication (CPM).

$$a \cdot b = b \cdot a \quad (4.6)$$

Property 4.3.2 – Associative Property of Multiplication (APM).

$$a \cdot b \cdot c = (a \cdot b) \cdot c \quad (4.7a)$$

$$a \cdot b \cdot c = a \cdot (b \cdot c) \quad (4.7b)$$

Property 4.3.3 – Distributive Property Expanding (DPE).

$$a(b + c) = ab + ac \quad (4.8a)$$

$$(b + c)a = ba + ca \quad (4.8b)$$

Property 4.3.4 – Multiplicative Identity (Mid).

$$a = 1a \quad (4.9a)$$

$$1a = a \quad (4.9b)$$

- R** If the coefficient of a univariate monomial is the multiplicative identity 4.9a, 1, then it is not shown in its canonical form.

$$\begin{aligned} C_k x^k &= C_k x^k \\ &= 1x^k \\ &= x^k \end{aligned}$$

Property 4.3.5 – Multiplicative Inverse (MI).

$$a \cdot \frac{1}{a} = 1 \quad (4.10a)$$

$$a \cdot a^{-1} = 1 \quad (4.10b)$$

Property 4.3.6 – Zero Product (ZPr).

$$\text{if } a \cdot b = 0, \text{ then } a = 0 \text{ or } b = 0 \quad (4.11a)$$

4.4 Properties of Subtraction

Definition 4.4.1 – Definition of Subtraction (DOS).

$$a - b = a + \neg b \quad (4.12a)$$

$$a + \neg b = a - b \quad (4.12b)$$

4.5 Properties of Powers

Property 4.5.1 – Power Inverse (Pold).

$$1 = b^0 \quad (4.13a)$$

$$b^0 = 1 \quad (4.13b)$$

4.6 Properties of Equality

Property 4.6.1 – Reflexive Property of Equality (RPE).

$$a = a \quad (4.14a)$$

Property 4.6.2 – Substitution Property of Equality (SPE).

Given $a = b$, then

$$E(a) = E(b) \quad (4.15)$$

$E(x)$ represents any expression.

Property 4.6.3 – Symmetric Property of Equality (SyPE).

$$a = b \quad \text{then} \quad b = a \quad (4.16a)$$

Property 4.6.4 – Transitive Property of Equality (TPE).

$$\text{if } a = b \quad \text{and} \quad b = c \quad \text{then} \quad a = c \quad (4.17a)$$

Property 4.6.5 – Zero Factor Property (ZFP).

$$\text{if } a \cdot b = 0 \text{ then } a = 0 \text{ or } b = 0 \quad (4.18a)$$

4.7 Properties of Inequality

Property 4.7.1 – Substitution Property of Inequality (SPIn).

$$a < b \text{ then } a + c < b + c \quad (4.19a)$$

$$a < b \text{ and } c > 0, \text{ then } ca < cb \quad (4.19b)$$

$$a < b \text{ and } c < 0, \text{ then } ca > cb \quad (4.19c)$$

Property 4.7.2 – Transitive Property of Inequality (TPIn).

$$\text{if } a < b \text{ and } b < c \text{ then } a > c \quad (4.20a)$$

5. Identities

5.1 Power Identities

Identity 5.1.1 – Power of Power (PoPo).

$$(b^m)^k = b^{m \cdot k} \quad (5.1a)$$

$$b^{m \cdot k} = (b^m)^k \quad (5.1b)$$

Identity 5.1.2 – Power of a Product (PoPr).

$$(a \cdot b)^k = a^k \cdot b^k \quad (5.2a)$$

$$a^k \cdot b^k = (a \cdot b)^k \quad (5.2b)$$

Identity 5.1.3 – Product Common Base Powers (PrCBPo).

$$b^m \cdot b^n = b^{m+n} \quad (5.3a)$$

$$b^{m+n} = b^m \cdot b^n \quad (5.3b)$$

Identity 5.1.4 – Quotient Common Base Powers (QCBPo).

$$\frac{b^m}{b^n} = b^{m-n} \quad (5.4a)$$

$$b^{m-n} = \frac{b^m}{b^n} \quad (5.4b)$$

Identity 5.1.5 – Power of a Quotient of Powers (PoQPo).

$$\left(\frac{a^m}{b^n}\right)^k = \frac{a^{m \cdot k}}{b^{n \cdot k}} \quad (5.5a)$$

$$\frac{a^{m \cdot k}}{b^{n \cdot k}} = \left(\frac{a^m}{b^n}\right)^k \quad (5.5b)$$

Identity 5.1.6 – Power of a Product of Powers (PoPrPo).

$$(a^m \cdot b^n)^k = a^{m \cdot k} \cdot b^{n \cdot k} \quad (5.6a)$$

$$a^{m \cdot k} \cdot b^{n \cdot k} = (a^m \cdot b^n)^k \quad (5.6b)$$

5.2 Logarithm Identities

Identity 5.2.1 – Logarithm Power of a Power (LPoPo).

$$\log_b x^n = n \log_b x \quad (5.7a)$$

$$n \log_b x = \log_b x^n \quad (5.7b)$$

Identity 5.2.2 – Logarithm Product of Common Base Powers (LPrCBPo).

$$\log_b(mn) = \log_b m + \log_b n \quad (5.8a)$$

$$\log_b m + \log_b n = \log_b(mn) \quad (5.8b)$$

Identity 5.2.3 – Logarithm Quotient of Common Base Powers (LQCBPo).

$$\log_b \left(\frac{m}{n} \right) = \log_b m - \log_b n \quad (5.9a)$$

$$\log_b m - \log_b n = \log_b \left(\frac{m}{n} \right) \quad (5.9b)$$

5.3 Trigonometric Identities

Identity 5.3.1 – Trigonometric Reciprocal Identities (TRId).

$$\sin \theta = \frac{1}{\csc \theta} \quad (5.10a)$$

$$\cos \theta = \frac{1}{\sec \theta} \quad (5.10b)$$

$$\cot \theta = \frac{1}{\tan \theta} \quad (5.10c)$$

$$\csc \theta = \frac{1}{\sin \theta} \quad (5.10d)$$

$$\sec \theta = \frac{1}{\cos \theta} \quad (5.10e)$$

$$\tan \theta = \frac{1}{\cot \theta} \quad (5.10f)$$

Identity 5.3.2 – Trigonometric Pythagorean Identities (TPythagId).

$$\sin^2 \theta + \cos^2 \theta = 1 \quad (5.11a)$$

$$\sec^2 \theta = \tan^2 \theta + 1 \quad (5.11b)$$

$$\csc^2 \theta = 1 + \cot^2 \theta \quad (5.11c)$$

Identity 5.3.3 – Trigonometric Tangent Identity (TanId).

$$\tan \theta = \frac{\sin \theta}{\cos \theta} \quad (5.12a)$$

Identity 5.3.4 – Trigonometric Cotangent Identity (CotId).

$$\cot \theta = \frac{\cos \theta}{\sin \theta} \quad (5.13a)$$

Identity 5.3.5 – Sine Double Angle Identity (SinDAId).

$$\sin 2\theta = 2 \sin \theta \cos \theta \quad (5.14a)$$

Identity 5.3.6 – Cosine Double Angle Identity (CosDAId).

$$\cos 2\theta = \cos^2 \theta - \sin^2 \theta \quad (5.15a)$$

$$= 1 - 2 \sin^2 \theta \quad (5.15b)$$

$$= 2 \cos^2 \theta - 1 \quad (5.15c)$$

Identity 5.3.7 – Tangent Double Angle Identity (TanDAId).

$$\tan 2\theta = \frac{2 \tan \theta}{1 - \tan^2 \theta} \quad (5.16a)$$

Identity 5.3.8 – Sine Sum of Angles Identity (SinSAId).

$$\sin(\theta + \phi) = \sin \theta \cos \phi + \cos \theta \sin \phi \quad (5.17a)$$

Identity 5.3.9 – Sine Difference of Angles Identity (SinDiffAId).

$$\sin(\theta - \phi) = \sin \theta \cos \phi - \cos \theta \sin \phi \quad (5.18a)$$

Identity 5.3.10 – Cosine Sum of Angles Identity (CosSAId).

$$\cos(\theta + \phi) = \cos \theta \cos \phi - \sin \theta \sin \phi \quad (5.19a)$$

Identity 5.3.11 – Cosine Difference of Angles Identity (CosDiffAId).

$$\cos(\theta - \phi) = \cos \theta \cos \phi + \sin \theta \sin \phi \quad (5.20a)$$

Identity 5.3.12 – Tangent Sum of Angles Identity (TanSAId).

$$\tan(\theta + \phi) = \frac{\tan \theta + \tan \phi}{1 - \tan \theta \tan \phi} \quad (5.21a)$$

Identity 5.3.13 – Tangent Difference of Angles Identity (TanDiffAld).

$$\tan(\theta - \phi) = \frac{\tan \theta - \tan \phi}{1 + \tan \theta \tan \phi} \quad (5.22a)$$

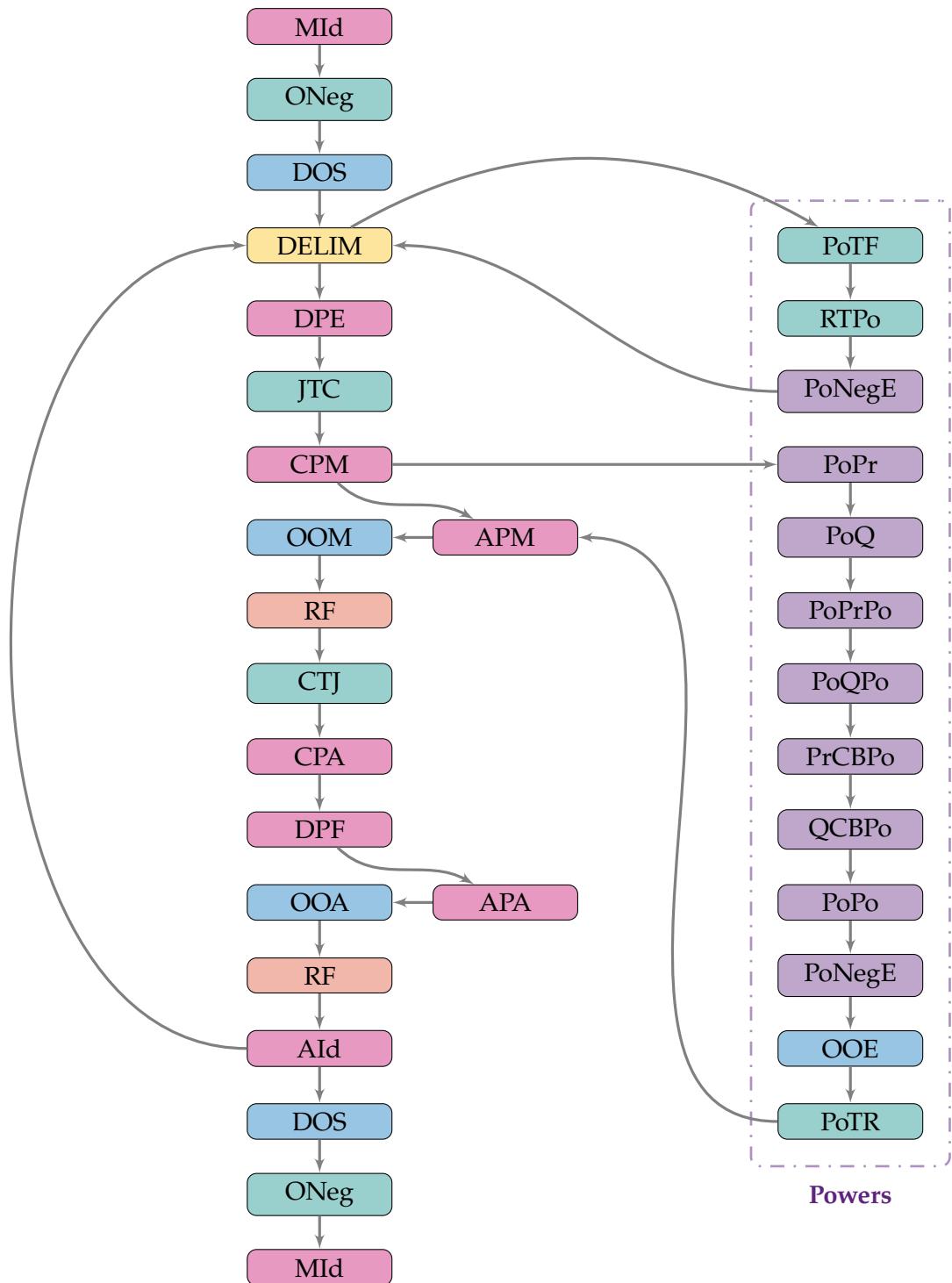


Figure 5.1: Simplifying Expressions Workflow:

■ Property, ■ Operation, ■ Notation, ■ Powers, ■ Delimiters, ■ Process, ■ Not Used

6. Limit Properties

6.1 Algebraic Limit Theorem

Rule 6.1.1 – Algebraic Limit Theorem of a Constant (ALTC). If $g(x) = a$, where a is a constant, then

$$\lim_{x \rightarrow c} [A] = A \quad (6.1)$$

Rule 6.1.2 – Algebraic Limit Theorem of a Sum (ALTS). If both the limits $\lim_{x \rightarrow c} g(x) = L_1$ and $\lim_{x \rightarrow c} h(x) = L_2$ exist, then

$$\lim_{x \rightarrow c} [g(x) + h(x)] = \lim_{x \rightarrow c} g(x) + \lim_{x \rightarrow c} h(x) \quad (6.2)$$

Rule 6.1.3 – Algebraic Limit Theorem of a Difference (ALTD). If both the limits $\lim_{x \rightarrow c} g(x) = L_1$ and $\lim_{x \rightarrow c} h(x) = L_2$ exist, then

$$\lim_{x \rightarrow c} [g(x) - h(x)] = \lim_{x \rightarrow c} g(x) - \lim_{x \rightarrow c} h(x) \quad (6.3)$$

Rule 6.1.4 – Algebraic Limit Theorem of a Product (ALTPr). If both the limits $\lim_{x \rightarrow c} g(x) = L_1$ and $\lim_{x \rightarrow c} h(x) = L_2$ exist, then

$$\lim_{x \rightarrow c} [g(x) \cdot h(x)] = \lim_{x \rightarrow c} g(x) \cdot \lim_{x \rightarrow c} h(x) \quad (6.4)$$

Rule 6.1.5 – Algebraic Limit Theorem of a Quotient (ALTQ). If both the limits $\lim_{x \rightarrow c} g(x) = L_1$ and $\lim_{x \rightarrow c} h(x) = L_2$ exist and $L_2 \neq 0$, then

$$\lim_{x \rightarrow c} \left[\frac{g(x)}{h(x)} \right] = \frac{\lim_{x \rightarrow c} g(x)}{\lim_{x \rightarrow c} h(x)} \quad (6.5)$$

7. Calculus Rules

7.1 Monomial Derivative Rules

Rule 7.1.1 – Derivative of a Constant (DC).

$$[c]' = 0 \quad (7.1)$$

$$\frac{d}{dx} [c] = 0 \quad (7.2)$$

Rule 7.1.2 – Derivative of a Constant Multiple (DCM).

$$[cf(x)]' = c[f(x)]' \quad (7.3)$$

$$\frac{d}{dx} [cf(x)] = c \frac{d}{dx} [f(x)] \quad (7.4)$$

Rule 7.1.3 – Derivative of a Power (DPo).

$$[x^n]' = nx^{n-1} \quad (7.5)$$

$$\frac{d}{dx} [x^n] = nx^{n-1} \quad (7.6)$$

7.2 Derivative Structural Rules

Rule 7.2.1 – Derivative of a Sum (DS).

$$[f(x) + g(x)]' = f'(x) + g'(x) \quad (7.7)$$

$$\frac{d}{dx} [f(x) + g(x)] = \frac{d}{dx} [f(x)] + \frac{d}{dx} [g(x)] \quad (7.8)$$

Rule 7.2.2 – Derivative of a Difference (DD).

$$[f(x) - g(x)]' = f'(x) - g'(x) \quad (7.9)$$

$$\frac{d}{dx} [f(x) - g(x)] = \frac{d}{dx} [f(x)] - \frac{d}{dx} [g(x)] \quad (7.10)$$

Rule 7.2.3 – Derivative of a Product (DPr).

$$[f(x)g(x)]' = f'(x)g(x) + f(x)g'(x) \quad (7.11)$$

$$\frac{d}{dx} [f(x)g(x)] = \frac{d}{dx} [f(x)]g(x) + f(x)\frac{d}{dx} [g(x)] \quad (7.12)$$

Rule 7.2.4 – Derivative of a Quotient (DQ).

$$\left[\frac{f(x)}{g(x)} \right]' = \frac{f'(x)g(x) - f(x)g'(x)}{[g(x)]^2} \quad (7.13)$$

$$\frac{d}{dx} \left[\frac{f(x)}{g(x)} \right] = \frac{\frac{d}{dx} [f(x)] g(x) - f(x) \frac{d}{dx} [g(x)]}{[g(x)]^2} \quad (7.14)$$

Rule 7.2.5 – Derivative of a Composite Function (DComp).

$$[f(g(x))]' = [g(x)]' [f(g(x))]' \quad (7.15)$$

$$\frac{d}{dx} [f(g(x))] = \frac{d}{dx} [g(x)] \frac{d}{dx} [f(g(x))] \quad (7.16)$$

7.3 Trigonometric Derivative Rules

Rule 7.3.1 – Derivative of Sine (DSin).

$$[\sin(x)]' = \cos(x) \quad (7.17)$$

$$\frac{d}{dx} [\sin(x)] = \cos(x) \quad (7.18)$$

Rule 7.3.2 – Derivative of Cosine (DCos).

$$[\cos(x)]' = -\sin(x) \quad (7.19)$$

$$\frac{d}{dx} [\cos(x)] = -\sin(x) \quad (7.20)$$

Rule 7.3.3 – Derivative of Tangent (DTan).

$$[\tan x]' = \sec^2 \quad (7.21)$$

$$\frac{d}{dx} [\tan x] = \sec^2 \quad (7.22)$$

Rule 7.3.4 – Derivative of Cosecant (DCsc).

$$[\csc x]' = -\csc x \cot x \quad (7.23)$$

$$\frac{d}{dx} [\csc x] = -\csc x \cot x \quad (7.24)$$

Rule 7.3.5 – Derivative of Secant (DSec).

$$[\sec x]' = \sec x \tan x \quad (7.25)$$

$$\frac{d}{dx} [\sec x] = \sec x \tan x \quad (7.26)$$

Rule 7.3.6 – Derivative of Cotangent (DCot).

$$[\cot x]' = -\csc^2 x \quad (7.27)$$

$$\frac{d}{dx} [\cot x] = -\csc^2 x \quad (7.28)$$

7.4 Logarithm Derivative Rules

Rule 7.4.1 – Derivative of a Logarithm (DL).

$$[\log_a x]' = \frac{1}{x \ln a} \quad (7.29)$$

$$\frac{d}{dx} [\log_a x] = \frac{1}{x \ln a} \quad (7.30)$$

Rule 7.4.2 – Derivative of a Natural Logarithm (DNL).

$$[\ln x]' = \frac{1}{x} \quad (7.31)$$

$$\frac{d}{dx} [\ln x] = \frac{1}{x} \quad (7.32)$$

7.5 Exponential Derivative Rules

Rule 7.5.1 – Derivative of an Exponential(DExp).

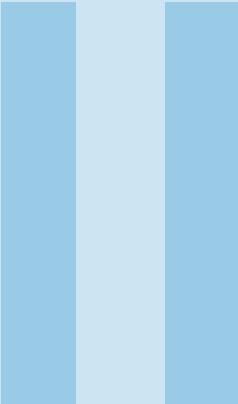
$$[a^x]' = a^x \ln a \quad (7.33)$$

$$\frac{d}{dx} [a^x] = a^x \ln a \quad (7.34)$$

Rule 7.5.2 – Derivative of a Natural Exponential(DNExp).

$$[e^x]' = e^x \quad (7.35)$$

$$\frac{d}{dx} [e^x] = e^x \quad (7.36)$$



Algebra

| | | | |
|-----------|---|-------|----|
| 8 | Simplifying Univariate Polynomials | | 35 |
| 8.1 | Simplifying Degree 0 Univariate Monomials | | |
| 8.2 | Simplifying Degree 1 Univariate Monomials | | |
| 8.3 | Simplifying Degree 2 Univariate Monomials | | |
| 8.4 | Simplifying Degree 3 Univariate Monomials | | |
| 8.5 | Simplifying Degree 1 Univariate Binomials | | |
| 8.6 | Simplifying Degree 2 Univariate Binomials | | |
| 8.7 | Simplifying Degree 2 Univariate Trinomials | | |
| 8.8 | Simplifying Degree n Univariate Polynomials | | |
| 9 | Simplifying Multivariate Monomials | | 61 |
| 9.1 | Simplifying Degree -1 Multivariate Monomials | | |
| 9.2 | Simplifying Degree 2 Multivariate Monomials | | |
| 9.3 | Simplifying Degree 2 Multivariate Binomials | | |
| 9.4 | Simplifying Degree 2 Multivariate Trinomials | | |
| 10 | Factoring Univariate Trinomials | | 65 |
| 11 | Solving Linear Equations | | 67 |
| 11.1 | Power Inverse | | |
| 12 | Solving Quadratic Equations | | 73 |
| 12.1 | Multiplicative Inverse | | |
| 12.2 | Completing The Square | | |

8. Simplifying Univariate Polynomials

The definition of a univariate polynomial expression is based on the expanded canonical form of some polynomial expression. It might be that the original expression might not be in the expanded canonical form, so a process called **simplifying by expanding** will be introduced to manipulate the expression such that it can be written in its expanded canonical form.

This process of simplifying by expanding polynomial expressions will be developed to the extent that it will be used to simplify multivariate polynomials. We will start by simplifying univariate monomial expressions.

8.1 Simplifying Degree 0 Univariate Monomials

Definition 8.1.1 – Indeterminate.

x

An indeterminate is a symbol that is treated as a variable, but does not stand for anything else but itself and is used as a placeholder.

- it does **not** designate a constant or a parameter
- it is **not** an unknown that could be solved for
- it is **not** a variable designating a function argument

[2]

Definition 8.1.2 – Degree of the Indeterminate.

x^k

The exponent of an indeterminate power, k is called the degree of the indeterminate.

Polynomial [4]

Definition 8.1.3 – Coefficient.

Cx^k

A coefficient, C is a real number multiplicative factor.

Definition 8.1.4 – Univariate Monomial.

$C_k x^k$

A univariate monomial is made up of two factors. The first factor of a monomial, C_k , is the **coefficient**. The second factor of each monomial, x^k , is an indeterminate raised to a non-negative integer power k .

Degree 0 univariate polynomial expressions are made up of univariate monomials, C_0 , called **constants**. The power identity is an indeterminate raised to a power of 0 has a value of 1. Thus, $x^0 = 1$ and results in the monomial $C_0 \cdot 1$. The canonical form of a product does not show the multiplicative identity factor, so what remains of this monomial product is only the coefficient factor C_0 and from now on will be referred to as a **constant**.

Degree 0 univariate polynomial expressions are usually a monomial in their canonical form if C_0 is a non-zero real number. The exception is if $C_0 = 0$, the additive identity, then the result is the zero polynomial, which can be considered a degree -1 polynomial.

The expression can be manipulated into its monomial canonical form by simplifying the expression. Simplifying the expression can be defined as evaluating the expression by following order of operations, which is the same as evaluating an arithmetic expression.

Definition 8.1.5 – Univariate Like Terms.

$$C_1x^k = C_2x^k$$

Two or more univariate monomials are defined as having like terms if each monomial has the same term, which will be the same indeterminate raised to the same positive integer power.

Sometimes the word **term** is used to describe monomials (including both the coefficient and the term), which may be confusing when trying to define like terms. For this reason, we will refer to the summands of a polynomial as monomials.

The monomials $5x^1$ and $3x^1$ can be described as having like terms because they share the common term x^1 . One could also say that $5x^1$ and $3x^1$ are like terms by definition and consequently giving the reader an impression that $5x^1$ and $3x^1$ are terms themselves.



- A degree 1 indeterminate does not display the multiplicative identity in the exponent when its in canonical form.

Example 8.1 – id:20141121-093747.

Express $13x^0$ in canonical form.



Solution:

8.2 Simplifying Degree 1 Univariate Monomials

Example 8.2 – id:20141120-202042.

Express $5x^1$ in canonical form

(S) _____

Solution:

$$5x \quad \text{MId(4.9b)}$$

■

Example 8.3 – id:20141121-093439.

Express $7x^1 + 5$ in canonical form.

(S) _____

Solution:

$$7x + 5 \quad \text{MId(4.9b)}$$

■

If the constant monomial is 0, the additive identity, then the canonical form of a degree 1 univariate polynomial is a degree 1 monomial.

Example 8.4 – id:20141120-203846.

Simplify by expanding $6x + 7x$

(S) _____

Solution:

Notice that the indeterminate of each monomial is of degree 1; however, the exponent 1 is not shown. The monomials $6x$ and $7x$ have a like term of x .

$$\begin{array}{ll} (6 + 7)x & \text{DPF(4.3a)} \\ 13x & \text{OOA(2.1)} \end{array}$$

Notice that the sum of two monomials that have like terms can be found by adding the coefficients of the monomials. The distributive property in the factoring direction provides some insight to why we can add the coefficients of monomials that have like terms.

S**Less Steps Solution:**

$$13x \quad \text{OOA(2.1)}$$

■

Example 8.5 – id:20141027-075159.

Simplify by expanding $7 \text{ cm} + 8 \text{ cm}$

S**Solution:**

$$(7 + 8) \text{ cm} \quad \text{DPF(4.3a)}$$
$$15 \text{ cm} \quad \text{OOA(2.1)}$$

■

R

Remember, if a monomial does not have a coefficient factor, then it's implied that the coefficient factor is 1, the multiplicative identity, and consequently its not explicitly shown.

Example 8.6 – id:20141121-185558.

Simplify by expanding $x + 5x$

S**Solution:**

It can be useful when simplifying expressions to make the multiplicative identity (MId) factor explicit.

$$\begin{array}{ll} 1x + 5x & \text{MId(4.9a)} \\ (1 + 5)x & \text{DPF(4.3a)} \\ 6x & \text{OOA(2.1)} \end{array}$$

S**Less Steps Solution:**

$$\begin{array}{ll} 1x + 5x & \text{MId(4.9a)} \\ 6x & \text{OOA(2.1)} \end{array}$$

As one becomes more experienced, there is no reason to make the multiplicative identity coefficient explicit.

(S) _____

Less Steps Solution:

$$6x \quad \text{OOA(2.1)}$$

■

Example 8.7 – id:20141121-190857.

Simplify by expanding $8x - 6x$

(S) _____

Solution:

$$\begin{array}{ll} 8x + -6x & \text{DOS(4.12a)} \\ (8 + -6)x & \text{DPF(4.3a)} \\ 2x & \text{OOA(2.1)} \end{array}$$

(S) _____

Less Steps Solution:

$$\begin{array}{ll} 8x + -6x & \text{DOS(4.12a)} \\ 2x & \text{OOA(2.1)} \end{array}$$

■

Example 8.8 – id:20141121-193636.

Simplify by expanding $3x - 5x$

(S) _____

Solution:

$$\begin{array}{ll} 3x + -5x & \text{DOS(4.12a)} \\ (3 + -5)x & \text{DPF(4.3a)} \\ -2x & \text{OOA(2.1)} \\ -2x & \text{ONeg(3.1b)} \end{array}$$

(S) _____

Less Steps Solution:

$$\begin{array}{ll} 3x + -5x & \text{DOS(4.12a)} \\ -2x & \text{OOA(2.1)} \\ -2x & \text{ONeg(3.1b)} \end{array}$$

(S)

Less Steps Solution:

$$-2x \quad \text{OOA(2.1)}$$

■

Example 8.9 – id:20141106-150622.Simplify by expanding $13x - x$

(S)

Solution:

$$\begin{array}{ll} 13x - 1x & \text{MId(4.9a)} \\ 13x + -1x & \text{DOS(4.12a)} \\ (13 + -1)x & \text{DPF(4.3a)} \\ 12x & \text{OOA(2.1)} \end{array}$$

(S)

Less Steps Solution:

$$\begin{array}{ll} 13x + -x & \text{DOS(4.12a)} \\ 12x & \text{OOA(2.1)} \end{array}$$

■

It is possible for a univariate monomial to have more than two terms in its non-canonical form. The associative property of addition will be used to help simplify these expressions.

Example 8.10 – id:20141121-184652.Simplify by expanding $3x + 7x + 8x$

(S)

| | |
|------------------|-----------|
| $(3x + 7x) + 8x$ | APA(4.2a) |
| $(3 + 7)x + 8x$ | DPF(4.3a) |
| $10x + 8x$ | OOA(2.1) |
| $(10 + 8)x$ | DPF(4.3a) |
| $18x$ | OOA(2.1) |

S**Less Steps Solution:**

| | |
|------------------|-----------|
| $(3x + 7x) + 8x$ | APA(4.2a) |
| $10x + 8x$ | OOA(2.1) |
| $18x$ | OOA(2.1) |

You might have noticed that this expression could be simplified in one step by adding the coefficient of the three monomials $3x$, $7x$ and $8x$, which have the like term x .

S**Less Steps Solution:**

| | |
|-------|----------|
| $18x$ | OOA(2.1) |
|-------|----------|

Example 8.11 – id:20141106-152020.

Simplify by expanding $4x - 2x - x$

S**Solution:**

| | |
|-------------------|------------|
| $4x - 2x - 1x$ | MId(4.9a) |
| $4x + -2x + -1x$ | DOS(4.12a) |
| $(4 + -2)x + -1x$ | DPF(4.3a) |
| $2x + -1x$ | OOA(2.1) |
| $(2 + -1)x$ | DPF(4.3a) |
| $1x$ | OOA(2.1) |
| x | MId(4.9b) |

S

Less Steps Solution:

$$\begin{array}{ll} 4x + -2x + -x & \text{DOS(4.12a)} \\ x & \text{OOA(2.1)} \end{array}$$

■

Example 8.12 – id:20141108-194431.Simplify by expanding $-3 \cdot 7x - 2x \cdot 4$

(S)

Solution:

$$\begin{array}{ll} -3 \cdot 7x - 2x \cdot 4 & \text{ONeg(3.1a)} \\ -3 \cdot 7x + -2x \cdot 4 & \text{DOS(4.12a)} \\ -3 \cdot 7 \cdot x + -2 \cdot x \cdot 4 & \text{JTC(3.5)} \\ -3 \cdot 7 \cdot x + -2 \cdot 4 \cdot x & \text{CPM(4.6)} \\ (-3 \cdot 7) \cdot x + (-2 \cdot 4) \cdot x & \text{APM(4.7a)} \\ -21 \cdot x + -8 \cdot x & \text{OOM(2.3)} \\ -21x + -8x & \text{CTJ(3.6)} \\ (-21 + -8)x & \text{DPF(4.3a)} \\ -29x & \text{OOA(2.1)} \\ -29x & \text{ONeg(3.1b)} \end{array}$$

(S)

Less Steps Solution:

$$\begin{array}{ll} -3 \cdot 7x + -2x \cdot 4 & \text{DOS(4.12a)} \\ -3 \cdot 7 \cdot x + -2 \cdot 4 \cdot x & \text{CPM(4.6)} \\ -21x + -8x & \text{OOM(2.3)} \\ -29x & \text{OOA(2.1)} \end{array}$$

■

Example 8.13 – id:20141108-194156.Simplify by expanding $3 \cdot 5x + 3x \cdot 4$

(S)

Solution:

| | |
|---|-----------|
| $3 \cdot 5 \cdot x + 3 \cdot x \cdot 4$ | JTC(3.5) |
| $3 \cdot 5 \cdot x + 3 \cdot 4 \cdot x$ | CPM(4.6) |
| $(3 \cdot 5) \cdot x + (3 \cdot 4) \cdot x$ | APM(4.7a) |
| $15 \cdot x + 12 \cdot x$ | OOM(2.3) |
| $15x + 12x$ | CTJ(3.6) |
| $(15 + 12)x$ | DPF(4.3a) |
| $27x$ | OOA(2.1) |

S**Less Steps Solution:**

| | |
|---|----------|
| $3 \cdot 5 \cdot x + 3 \cdot 4 \cdot x$ | CPM(4.6) |
| $15x + 12x$ | OOM(2.3) |
| $27x$ | OOA(2.1) |

Example 8.14 – id:20141108-173613.Simplify by expanding $8x \cdot 5$ **S****Solution:**

| | |
|-----------------------|-----------|
| $8 \cdot x \cdot 5$ | JTC(3.5) |
| $8 \cdot 5 \cdot x$ | CPM(4.6) |
| $(8 \cdot 5) \cdot x$ | APM(4.7a) |
| $40 \cdot x$ | OOM(2.3) |
| $40x$ | CTJ(3.6) |

8.3 Simplifying Degree 2 Univariate Monomials

Example 8.15 – id:20151018-184931.Simplify $x \cdot x$ **S**

Solution:

$$\begin{array}{ll}
 1x^1 \cdot 1x^1 & \text{MId(4.9a)} \\
 1x^{(1+1)} & \text{PrCBPo(5.3a)} \\
 1x^2 & \text{OOA(2.1)} \\
 x^2 & \text{MId(4.9b)}
 \end{array}$$

■

Example 8.16 – id:20141120-202842.Express by expanding $1x^2$ in canonical form.

(S) _____

Solution:

$$x^2 \quad \text{MId(4.9b)}$$

■

Example 8.17 – id:20141106-151138.Simplify by expanding $4x^2 + 12x^2$

(S) _____

Solution:

$$\begin{array}{ll}
 (4 + 12)x^2 & \text{DPF(4.3a)} \\
 16x^2 & \text{OOA(2.1)}
 \end{array}$$

(S) _____

Less Steps Solution:

$$16x^2 \quad \text{OOA(2.1)}$$

■

Example 8.18 – id:20141106-154547.Simplify by expanding $x^2 - x + x^2 + x$

(S) _____

Solution:

$$\begin{array}{ll}
 1x^2 - 1x + 1x^2 + 1x & \text{MId(4.9a)} \\
 1x^2 + \neg 1x + 1x^2 + 1x & \text{DOS(4.12a)} \\
 1x^2 + 1x^2 + \neg 1x + 1x & \text{CPA(4.1)} \\
 (1 + 1)x^2 + (\neg 1 + 1)x & \text{DPF(4.3a)} \\
 2x^2 + 0x & \text{OOA(2.1)} \\
 2x^2 & \text{AId(4.4b)}
 \end{array}$$

(S)

Less Steps Solution:

$$\begin{array}{ll}
 x^2 + \neg x + x^2 + x & \text{DOS(4.12a)} \\
 x^2 + x^2 + \neg x + x & \text{CPA(4.1)} \\
 2x^2 & \text{OOA(2.1)}
 \end{array}$$

■

Example 8.19 – id:20141108-194709.Simplify by expanding $-2x^4x - x \cdot -x^3$

(S)

Solution:

$$\begin{array}{ll}
 -2x^4x - 1x \cdot 1x^3 & \text{MId(4.9a)} \\
 \neg 2x^4x - 1x \cdot 1x^3 & \text{ONeg(3.1a)} \\
 \neg 2 \cdot x \cdot 4 \cdot x + \neg 1 \cdot x \cdot 1 \cdot x \cdot 3 & \text{JTC(3.5)} \\
 \neg 2 \cdot 4 \cdot x \cdot x + \neg 1 \cdot \neg 1 \cdot 3 \cdot x \cdot x & \text{CPM(4.6)} \\
 \neg 2 \cdot 4 \cdot x^2 + \neg 1 \cdot \neg 1 \cdot 3 \cdot x^2 & \text{PrCBPo(5.3a)} \\
 (\neg 2 \cdot 4) \cdot x^2 + (\neg 1 \cdot \neg 1 \cdot 3) x^2 & \text{APM(4.7a)} \\
 \neg 8x^2 + 3x^2 & \text{OOM(2.3)} \\
 (\neg 8 + 3)x^2 & \text{DPF(4.3a)} \\
 \neg 5x^2 & \text{OOA(2.1)} \\
 -5x^2 & \text{ONeg(3.1b)}
 \end{array}$$

(S)

Less Steps Solution:

| | |
|--|--------------|
| $-2x^4x + \neg x \cdot -x^3$ | DOS(4.12a) |
| $\neg 2 \cdot 4 \cdot x \cdot x + 3 \cdot \neg x \cdot \neg x$ | CPM(4.6) |
| $\neg 2 \cdot 4 \cdot x^2 + 3 \cdot x^2$ | PrCBPo(5.3a) |
| $\neg 8x^2 + 3x^2$ | OOM(2.3) |
| $-5x^2$ | OOA(2.1) |

Example 8.20 – id:20141108-191616.

Simplify by expanding $-5x \cdot 4x$

(S)

Solution:

| | |
|----------------------------------|--------------|
| $\neg 5x \cdot 4x$ | ONeg(3.1a) |
| $\neg 5 \cdot x \cdot 4 \cdot x$ | JTC(3.5) |
| $\neg 5 \cdot 4 \cdot x \cdot x$ | CPM(4.6) |
| $\neg 5 \cdot 4 \cdot x^2$ | PrCBPo(5.3a) |
| $(\neg 5 \cdot 4) \cdot x^2$ | APM(4.7a) |
| $\neg 20 \cdot x^2$ | OOM(2.3) |
| $\neg 20x^2$ | CTJ(3.6) |
| $-20x^2$ | ONeg(3.1b) |

(S)

Less Steps Solution:

| | |
|----------------------------------|--------------|
| $\neg 5 \cdot 4 \cdot x \cdot x$ | CPM(4.6) |
| $\neg 5 \cdot 4 \cdot x^2$ | PrCBPo(5.3a) |
| $-20x^2$ | OOM(2.3) |

8.4 Simplifying Degree 3 Univariate Monomials**8.5 Simplifying Degree 1 Univariate Binomials**

$$C_n x^n + C_{n-1} x^{n-1} + \cdots + C_k x^k + \cdots + C_2 x^2 + \textcolor{red}{C_1 x^1} + \underbrace{C_0}_{C_0 x^0}$$

Degree 1 univariate polynomial expressions can be expressed with at most two different terms and consequently this expression in its canonical form has at most two monomial summands – called a binomial.

Example 8.21 – id:20141109-090809.

Simplify by expanding $5(x + 4)$

S

Solution:

| | |
|---------------------------------|-----------|
| $5(1x + 4)$ | MId(4.9a) |
| $5 \cdot 1x + 5 \cdot 5$ | DPF(4.3a) |
| $5 \cdot 1 \cdot x + 5 \cdot 5$ | JTC(3.5) |
| $5 \cdot x + 25$ | OOM(2.3) |
| $5x + 25$ | CTJ(3.6) |

S

Less Steps Solution:

$$5x + 20 \quad \text{DPE}(4.8a)$$

■

Example 8.22 – id:20141109-091015.

Simplify by expanding $5(3x - 9)$

S

Solution:

| | |
|----------------------------------|------------|
| $5(3x + -9)$ | DOS(4.12a) |
| $5 \cdot 3x + 5 \cdot -9$ | DPE(4.8a) |
| $5 \cdot 3 \cdot x + 5 \cdot -9$ | JTC(3.5) |
| $15 \cdot x + -45$ | OOM(2.3) |
| $15x + -45$ | CTJ(3.6) |
| $15x - 45$ | DOS(4.12b) |

S

Less Steps Solution:

| | |
|--------------|------------|
| $5(3x + -9)$ | DOS(4.12a) |
| $15x + -40$ | DPE(4.8a) |
| $15x - 40$ | DOS(4.12b) |

Example 8.23 – id:20141109-092448.

Simplify by expanding $-(5x + 7)$

(S)

Solution:

$$\begin{array}{ll} \neg 1(5x + 7) & \text{MId(4.9a)} \\ \neg 1 \cdot 5x + \neg 1 \cdot 7 & \text{DPE(4.8a)} \\ \neg 1 \cdot 5 \cdot x + \neg 1 \cdot 7 & \text{JTC(3.5)} \\ \neg 5 \cdot x + \neg 7 & \text{OOM(2.3)} \\ \neg 5x + \neg 7 & \text{CTJ(3.6)} \\ \neg 5x - 7 & \text{DOS(4.12b)} \\ -5x - 7 & \text{ONeg(3.1b)} \end{array}$$

(S)

Less Steps Solution:

$$-5x - 7 \quad \text{DPE(4.8a)}$$

Example 8.24 – id:20141109-092651.

Simplify by expanding $-13(7x - 9)$

(S)

Solution:

$$\begin{array}{ll} \neg 13(7x + \neg 9) & \text{DOS(4.12a)} \\ \neg 13 \cdot 7x + \neg 13 \cdot \neg 9 & \text{DPE(4.8a)} \\ \neg 13 \cdot 7 \cdot x + \neg 13 \cdot \neg 9 & \text{JTC(3.5)} \\ \neg 91 \cdot x + 117 & \text{OOM(2.3)} \\ \neg 91x + 117 & \text{CTJ(3.6)} \\ -91x + 117 & \text{ONeg(3.1b)} \end{array}$$

(S)

Less Steps Solution:

$$\begin{array}{ll} -13(7x + -9) & \text{DOS}(4.12a) \\ -91x + 117 & \text{DPE}(4.8a) \end{array}$$

■

Example 8.25 – id:20141109-092910.Simplify by expanding $a(x + b)$, where $a, b \in \mathbb{Z}$

(S)

Solution:

$$\begin{array}{ll} a(1x + b) & \text{MId}(4.9a) \\ a \cdot 1x + a \cdot b & \text{DPE}(4.8a) \\ a \cdot 1 \cdot x + a \cdot b & \text{JTC}(3.5) \\ 1 \cdot a \cdot x + a \cdot b & \text{CPM}(4.6) \\ 1ax + ab & \text{JTC}(3.5) \\ ax + ab & \text{MId}(4.9b) \end{array}$$

■

Less Steps Solution:

$$ax + ab \quad \text{DPE}(4.8a)$$

■

Example 8.26 – id:20141109-093220.Simplify by expanding $5(x + 2) + 4$

(S)

Solution:

$$\begin{array}{ll} 5(1x + 2) + 4 & \text{MId}(4.9a) \\ 5 \cdot 1x + 5 \cdot 2 + 4 & \text{DPE}(4.8a) \\ 5 \cdot 1 \cdot x + 5 \cdot 2 + 4 & \text{JTC}(3.5) \\ 5 \cdot x + 10 + 4 & \text{OOM}(2.3) \\ 5x + 10 + 4 & \text{CTJ}(3.6) \\ 5x + 14 & \text{OOA}(2.1) \end{array}$$

■

S**Less Steps Solution:**

$$\begin{array}{ll} 5x + 10 + 4 & \text{DPE(4.8a)} \\ 5x + 14 & \text{OOA(2.1)} \end{array}$$

■

Example 8.27 – id:20141109-093419.Simplify by expanding $7x + 5(4x + 8)$ **S****Solution:**

$$\begin{array}{ll} 7x + 5 \cdot 4x + 5 \cdot 8 & \text{DPE(4.8a)} \\ 7 \cdot x + 5 \cdot 4 \cdot x + 5 \cdot 8 & \text{JTC(3.5)} \\ 7 \cdot x + 20 \cdot x + 40 & \text{OOM(2.3)} \\ 7x + 20x + 40 & \text{CTJ(3.6)} \\ (7 + 20)x + 40 & \text{DPF(4.3a)} \\ 27x + 40 & \text{OOA(2.1)} \end{array}$$

■

Example 8.28 – id:20141109-094928.Simplify by expanding $4(3x + 4) + x + 6$ **S****Solution:**

$$\begin{array}{ll} 4(3x + 4) + 1x + 6 & \text{MId(4.9a)} \\ 4 \cdot 3x + 4 \cdot 4 + 1x + 6 & \text{DPE(4.8a)} \\ 4 \cdot 3 \cdot x + 4 \cdot 4 + 1 \cdot x + 6 & \text{JTC(3.5)} \\ 12 \cdot x + 16 + 1 \cdot x + 6 & \text{OOM(2.3)} \\ 12x + 16 + 1x + 6 & \text{CTJ(3.6)} \\ 12 + 1x + 16 + 6 & \text{CPA(4.1)} \\ (12 + 1)x + 16 + 6 & \text{DPF(4.3a)} \\ 13x + 22 & \text{OOA(2.1)} \end{array}$$

S

Less Steps Solution:

$$\begin{array}{ll} 12x + 16 + x + 6 & \text{DPE(4.8a)} \\ 12x + x + 16 + 6 & \text{CPA(4.1)} \\ 13x + 22 & \text{OOA(2.1)} \end{array}$$

■

Example 8.29 – id:20141109-095151.Simplify by expanding $5(x - 4) + 3x - 5$

(S)

Solution:

$$\begin{array}{ll} 5(1x - 4) + 3x - 5 & \text{MId(4.9a)} \\ 5(1x + -4) + 3x + -5 & \text{DOS(4.12a)} \\ 5 \cdot 1x + 5 \cdot -4 + 3x + -5 & \text{DPE(4.8a)} \\ 5 \cdot 1 \cdot x + 5 \cdot -4 + 3 \cdot x + -5 & \text{JTC(3.5)} \\ 5 \cdot x + -20 + 3 \cdot x + -5 & \text{OOM(2.3)} \\ 5x + -20 + 3x + -5 & \text{JTC(3.5)} \\ 5x + 3x + -20 + -5 & \text{CPA(4.1)} \\ (5 + 3)x + -20 + -5 & \text{DPF(4.3a)} \\ 8x + -25 & \text{OOA(2.1)} \\ 8x - 25 & \text{DOS(4.12b)} \end{array}$$

(S)

Less Steps Solution:

$$\begin{array}{ll} 5(x + -4) + 3x + -5 & \text{DOS(4.12a)} \\ 5x + -20 + 3x + -5 & \text{DPE(4.8a)} \\ 5x + 3x + -20 + -5 & \text{CPA(4.1)} \\ 8x + -25 & \text{OOA(2.1)} \\ 8x - 25 & \text{DOS(4.12b)} \end{array}$$

■

Example 8.30 – id:20141109-095536.Simplify by expanding $8x - 5 - 4(x - 3)$

(S)

Solution:

| | |
|---|------------|
| $8x - 5 - 4(1x - 3)$ | MId(4.9a) |
| $8x + -5 + -4(1x + -3)$ | DOS(4.12a) |
| $8x + -5 + -4 \cdot 1x + -4 \cdot -3$ | DPE(4.8a) |
| $8 \cdot x + -5 + -4 \cdot 1 \cdot x + -4 \cdot -3$ | JTC(3.5) |
| $8 \cdot x + -5 + -4 \cdot x + 12$ | OOM(2.3) |
| $8x + -5 + -4x + 12$ | CTJ(3.6) |
| $8x + -4x + -5 + 12$ | CPA(4.1) |
| $(8 + -4)x + -5 + 12$ | DPF(4.3a) |
| $4x + 7$ | OOA(2.1) |

S

Less Steps Solution:

| | |
|------------------------|------------|
| $8x + -5 + -4(x + -3)$ | DOS(4.12a) |
| $8x + -5 + -4x + 12$ | DPE(4.8a) |
| $8x + -4x + -5 + 12$ | CPA(4.1) |
| $4x + 7$ | OOA(2.1) |

■

Example 8.31 – id:20141109-095842.

Simplify by expanding $5(x + 3) + 3(x + 2)$

S

Solution:

| | |
|---|-----------|
| $5 \cdot x + 5 \cdot 3 + 3 \cdot x + 3 \cdot 2$ | DPE(4.8a) |
| $5 \cdot x + 15 + 3 \cdot x + 6$ | OOM(2.3) |
| $5x + 15 + 3x + 6$ | CTJ(3.6) |
| $5x + 3x + 15 + 6$ | CPA(4.1) |
| $(3 + 5)x + 15 + 6$ | DPF(4.3a) |
| $8x + 21$ | OOA(2.1) |

S

Less Steps Solution:

$$\begin{array}{ll} 5x + 15 + 3x + 6 & \text{DPE(4.8a)} \\ 5x + 3x + 15 + 6 & \text{CPA(4.1)} \\ 8x + 21 & \text{OOA(2.1)} \end{array}$$

■

8.6 Simplifying Degree 2 Univariate Binomials**Example 8.32 – id:20141106-152339.**

Simplify by expanding $3x^2 + 2x + 5x^2 + 4x$

(S) _____

Solution:

$$\begin{array}{ll} 3x^2 + 5x^2 + 2x + 4x & \text{CPA(4.1)} \\ (3 + 5)x^2 + (2 + 4)x & \text{DPF(4.3a)} \\ 8x^2 + 6x & \text{OOA(2.1)} \end{array}$$

If needed we could continue and express it in the simplified factored form using the distributive property

$$(4x + 3)2x \quad \text{DPF(4.3a)}$$

(S) _____

Less Steps Solution:

$$\begin{array}{ll} 3x^2 + 5x^2 + 2x + 4x & \text{CPA(4.1)} \\ 8x^2 + 6x & \text{OOA(2.1)} \end{array}$$

■

Example 8.33 – id:20141107-121834.

Simplify by expanding $(\sqrt{9 - x^2})^2$

(S) _____

Solution:

$$\begin{aligned}
 & (\sqrt{9 - 1x^2})^2 && \text{MId(4.9a)} \\
 & (\sqrt{9 + -1x^2})^2 && \text{DOS(4.12a)} \\
 & [(9 + -x^2)^{\frac{1}{2}}]^2 && \text{RTPo(3.12)} \\
 & 9 + -1x^2 && \text{PoPo(5.1a)} \\
 & -1x^2 + 9 && \text{CPA(4.1)} \\
 & -x^2 + 9 && \text{MId(4.9a)} \\
 & -x^2 + 9 && \text{ONeg(3.1b)}
 \end{aligned}$$

(S)**Less Steps Solution:**

$$9 - x^2 \quad \text{PoPo(5.1a)}$$

It might be easier to view this using a variable substitution for the radicand, $9 - x^2$. Let $k = 9 + -1x^2$.

$$\begin{aligned}
 & (\sqrt{k})^2 && \text{MId(4.9a)} \\
 & (\sqrt{k})^2 && \text{DOS(4.12a)} \\
 & [(k)^{\frac{1}{2}}]^2 && \text{RTPo(3.12)} \\
 & k && \text{PoPo(5.1a)} \\
 & 9 + -1x^2 && \text{CPA(4.1)} \\
 & -1x^2 + 9 && \text{CPA(4.1)} \\
 & -x^2 + 9 && \text{MId(4.9b)} \\
 & -x^2 + 9 && \text{ONeg(3.1b)}
 \end{aligned}$$

(D)

Dependencies:example ??-20141105-144223

Example 8.34 – id:20141209-145211.Simplify by expanding $2x(2x + 4) + x^2 \cdot 2 \cdot 1 + 0$ **(S)**

Solution:

$$\begin{array}{ll}
 2x \cdot 2x + 2x \cdot 4 + x^2 \cdot 2 \cdot 1 + 0 & \text{DPE(4.8a)} \\
 2 \cdot x \cdot 2 \cdot x + 2 \cdot x \cdot 4 + x^2 \cdot 2 \cdot 1 + 0 & \text{JTC(3.5)} \\
 2 \cdot 2 \cdot x \cdot x + 2 \cdot 4 \cdot x + 2 \cdot 1 \cdot x^2 + 0 & \text{CPM(4.6)} \\
 2 \cdot 2 \cdot x^2 + 2 \cdot 4 \cdot x + 2 \cdot 1 \cdot x^2 + 0 & \text{PrCBPo(5.3a)} \\
 4 \cdot x^2 + 8 \cdot x + 2 \cdot x^2 + 0 & \text{OOM(2.3)} \\
 4x^2 + 8x + 2x^2 + 0 & \text{CTJ(3.6)} \\
 4x^2 + 2x^2 + 8x + 0 & \text{CPA(4.1)} \\
 (4 + 2)x^2 + 8x + 0 & \text{DPF(4.3a)} \\
 6x^2 + 8x + 0 & \text{OOA(2.1)} \\
 6x^2 + 8x & \text{AId(4.4b)}
 \end{array}$$

D

Dependencies:example 15.7-20141209-144203



8.7 Simplifying Degree 2 Univariate Trinomials

Example 8.35 – id:20141109-133008.Simplify by expanding $(x + 5)(x - 8)$ **S****Solution:**

$$\begin{array}{ll}
 (1x + 5)(1x - 8) & \text{MId(4.9a)} \\
 (1x + 5)(1x + \neg 8) & \text{DOS(4.12a)} \\
 1x(1x + \neg 8) + 5(1x + \neg 8) & \text{DPE(4.8b)} \\
 1x \cdot 1x + 1x \cdot \neg 8 + 5 \cdot 1x + 5 \cdot \neg 8 & \text{DPE(4.8a)} \\
 1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot \neg 8 + 5 \cdot 1 \cdot x + 5 \cdot \neg 8 & \text{JTC(3.5)} \\
 1 \cdot 1 \cdot x \cdot x + \neg 8 \cdot 1 \cdot x + 1 \cdot 5 \cdot x + \neg 8 \cdot 5 & \text{CPM(4.6)} \\
 1 \cdot 1 \cdot x^2 + \neg 8 \cdot 1 \cdot x + 1 \cdot 5 \cdot x + \neg 8 \cdot 5 & \text{PrCBPo(5.3a)} \\
 1 \cdot x^2 + \neg 8x + 5x + \neg 40 & \text{OOM(2.3)} \\
 1x^2 + \neg 8x + 5x + \neg 40 & \text{CTJ(3.6)} \\
 1x^2 + \neg 3x + \neg 40 & \text{OOA(2.1)} \\
 1x^2 - 3x - 40 & \text{DOS(4.12b)} \\
 x^2 - 3x - 40 & \text{MId(4.9b)}
 \end{array}$$

S

Less Steps Solution:

$$\begin{array}{ll}
 (x + 5)(x + -8) & \text{DOS(4.12a)} \\
 x(x + -8) + 5(x + -8) & \text{DPE(4.8b)} \\
 x^2 + -8x + 5x + -40 & \text{DPE(4.8a)} \\
 x^2 - 3x - 40 & \text{OOA(2.1)}
 \end{array}$$

Example 8.36 – id:20141109-133316.

Simplify by expanding $(x + a)(x + b)$, where $a, b \in \mathbb{Z}$

(S)

Solution:

$$\begin{array}{ll}
 (1x + a)(1x + b) & \text{MId(4.9a)} \\
 1x(1x + b) + a(1x + b) & \text{DPE(4.8b)} \\
 1x \cdot 1x + 1x \cdot b + a \cdot 1x + a \cdot b & \text{DPE(4.8a)} \\
 1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot b + a \cdot 1 \cdot x + a \cdot b & \text{JTC(3.5)} \\
 1 \cdot 1 \cdot x \cdot x + 1 \cdot b \cdot x + 1 \cdot a \cdot x + a \cdot b & \text{CPM(4.6)} \\
 1 \cdot 1 \cdot x^2 + 1 \cdot b \cdot x + 1 \cdot a \cdot x + a \cdot b & \text{PrCBPo(5.3a)} \\
 1 \cdot x^2 + 1 \cdot b \cdot x + 1 \cdot a \cdot x + a \cdot b & \text{OOM(2.3)} \\
 1x^2 + 1bx + 1ax + ab & \text{CTJ(3.6)} \\
 1x^2 + (1b + 1a)x + ab & \text{DPF(4.3a)} \\
 x^2 + (b + a)x + ab & \text{MId(4.9b)}
 \end{array}$$

(S)

Less Steps Solution:

$$\begin{array}{ll}
 x(x + b) + a(x + b) & \text{DPE(4.8b)} \\
 x^2 + (b + a)x + ab & \text{DPE(4.8a)}
 \end{array}$$

Example 8.37 – id:20141109-140659.

Simplify by expanding $(2x + 3)(5x + 13)$

(S)

Solution:

$$\begin{aligned}
 & 2x(5x + 13) + 3(5x + 13) && \text{DPE(4.8b)} \\
 & 2x \cdot 5x + 2x \cdot 13 + 3 \cdot 5x + 3 \cdot 13 && \text{DPE(4.8a)} \\
 & 2 \cdot x \cdot 5 \cdot x + 2 \cdot x \cdot 13 + 3 \cdot 5 \cdot x + 3 \cdot 13 && \text{JTC(3.5)} \\
 & 2 \cdot 5 \cdot x \cdot x + 2 \cdot 13 \cdot x + 5 \cdot 3 \cdot x + 3 \cdot 13 && \text{CPM(4.6)} \\
 & 2 \cdot 5 \cdot x^2 + 2 \cdot 13 \cdot x + 5 \cdot 3 \cdot x + 3 \cdot 13 && \text{PrCBPo(5.3a)} \\
 & 10 \cdot x^2 + 26 \cdot x + 16 \cdot x + 39 && \text{OOM(2.3)} \\
 & 10x^2 + 26x + 15x + 39 && \text{CTJ(3.6)} \\
 & 10x^2 + 41x + 39 && \text{OOA(2.1)}
 \end{aligned}$$

S**Less Steps Solution:**

$$\begin{aligned}
 & 2x(5x + 13) + 3(5x + 13) && \text{DPE(4.8b)} \\
 & 10x^2 + 26x + 15x + 39 && \text{DPE(4.8a)} \\
 & 10x^2 + 41x + 39 && \text{OOA(2.1)}
 \end{aligned}$$

Example 8.38 – id:20141109-141019.Simplify by expanding $(-3x - 5)(7x + 8)$ **S****Solution:**

$$\begin{aligned}
 & (-3x - 5)(7x + 8) && \text{ONeg(3.1a)} \\
 & (-3x + -5)(7x + 8) && \text{DOS(4.12a)} \\
 & -3x(7x + 8) + -5(7x + 8) && \text{DPE(4.8b)} \\
 & -3x \cdot 7x + -3x \cdot 8 + -5 \cdot 7x + -5 \cdot 8 && \text{DPE(4.8a)} \\
 & -3 \cdot x \cdot 7 \cdot x + -3 \cdot x \cdot 8 + -5 \cdot 7 \cdot x + -5 \cdot 8 && \text{JTC(3.5)} \\
 & -3 \cdot 7 \cdot x \cdot x + -3 \cdot 8 \cdot x + -5 \cdot 7 \cdot x + -5 \cdot 8 && \text{CPM(4.6)} \\
 & -3 \cdot 7 \cdot x^2 + -3 \cdot 8 \cdot x + -5 \cdot 7 \cdot x + -5 \cdot 8 && \text{PrCBPo(5.3a)} \\
 & -21 \cdot x^2 + -24 \cdot x + -35 \cdot x + -40 && \text{OOM(2.3)} \\
 & -21x^2 + -24x + -35x + -40 && \text{CTJ(3.6)} \\
 & -21x^2 + -59x + -40 && \text{OOA(2.1)} \\
 & -21x^2 - 59x - 40 && \text{DOS(4.12b)} \\
 & -21x^2 - 59x - 40 && \text{ONeg(3.1b)}
 \end{aligned}$$

S**Less Steps Solution:**

$$\begin{array}{ll}
 (-3x + -5)(7x + 8) & \text{DOS(4.12a)} \\
 -3x(7x + 8) + -5(7x + 8) & \text{DPE(4.8b)} \\
 -21x^2 + -24x + -35x + -40 & \text{CTJ(4.8a)} \\
 -21x^2 - 59x - 40 & \text{OOA(2.1)}
 \end{array}$$

■

Example 8.39 – id:20141109-141347.Simplify by expanding $(ax + b)(cx + d)$, where $a, b, c, d \in \mathbb{Z}$ **S****Solution:**

$$\begin{array}{ll}
 ax(cx + d) + b(cx + d) & \text{DPE(4.8b)} \\
 ax \cdot cx + ax \cdot d + b \cdot cx + b \cdot d & \text{DPE(4.8a)} \\
 a \cdot x \cdot c \cdot x + a \cdot x \cdot d + b \cdot c \cdot x + b \cdot d & \text{JTC(3.5)} \\
 a \cdot c \cdot x \cdot x + a \cdot d \cdot x + b \cdot c \cdot x + b \cdot d & \text{CPM(4.6)} \\
 a \cdot c \cdot x^2 + a \cdot d \cdot x + b \cdot c \cdot x + b \cdot d & \text{PrCBPo(5.3a)} \\
 acx^2 + adx + bcx + bd & \text{CTJ(3.6)} \\
 acx^2 + (ad + bc)x + bd & \text{DPF(4.3a)}
 \end{array}$$

S**Less Steps Solution:**

$$\begin{array}{ll}
 ax(cx + d) + b(cx + d) & \text{DPE(4.8b)} \\
 acx^2 + (ad + bc)x + bd & \text{DPE(4.8a)}
 \end{array}$$

■

Example 8.40 – id:20141105-161225.Simplify by expanding $\left(2 - \frac{x}{2}\right)^2$.**S**

Solution:

$$\begin{aligned}
 & \left(2 - \frac{1x}{2}\right)^2 && \text{MId(4.9a)} \\
 & \left(2 + -\frac{1x}{2}\right)^2 && \text{DOS(4.12a)} \\
 & \left(2 + -\frac{1x}{2}\right)\left(2 + -\frac{1x}{2}\right) && \text{PoTF(3.9)} \\
 & 2\left(2 + -\frac{1x}{2}\right) + -\frac{1x}{2}\left(2 + -\frac{1x}{2}\right) && \text{DPE(4.8b)} \\
 & 2 \cdot 2 + 2 \cdot -\frac{1x}{2} + -\frac{1x}{2} \cdot 2 + -\frac{1x}{2} \cdot -\frac{1x}{2} && \text{DPE(4.8a)} \\
 & 2 \cdot 2 + 2 \cdot -\frac{1}{2} \cdot x + -\frac{1}{2} \cdot x \cdot 2 + -\frac{1}{2} \cdot x \cdot -\frac{1}{2} \cdot x && \text{JTC(3.5)} \\
 & 2 \cdot 2 + 2 \cdot -\frac{1}{2} \cdot x + -\frac{1}{2} \cdot 2 \cdot x + -\frac{1}{2} \cdot -\frac{1}{2} \cdot x \cdot x && \text{CPM(4.6)} \\
 & 2 \cdot 2 + 2 \cdot -\frac{1}{2} \cdot x + -\frac{1}{2} \cdot 2 \cdot x + -\frac{1}{2} \cdot -\frac{1}{2} \cdot x^2 && \text{PrCBPo(5.3a)} \\
 & 4 + -1 \cdot x + -1 \cdot x + \frac{1}{4} \cdot x^2 && \text{OOM(2.3)} \\
 & 4 + -1x + -1x + \frac{1}{4}x^2 && \text{CTJ(3.6)} \\
 & \frac{1}{4}x^2 + -1x + -1x + 4 && \text{CPA(4.1)} \\
 & \frac{1}{4}x^2 + -2x + 4 && \text{OOA(2.1)} \\
 & \frac{1}{4}x^2 - 2x + 4 && \text{DOS(4.12b)}
 \end{aligned}$$

(S)

Less Steps Solution:

$$\begin{aligned}
 & 7x + 20x + 40 && \text{DPE(4.8a)} \\
 & 27x + 40 && \text{OOA(2.1)}
 \end{aligned}$$

8.8 Simplifying Degree n Univariate Polynomials

Definition 8.8.1 – Univariate Polynomial Expression.

$$\sum_{k=0}^n C_k x^n = C_n x^n + C_{n-1} x^{n-1} + \cdots + C_k x^k + \cdots + C_2 x^2 + C_1 x^1 + \underbrace{C_0}_{C_0 x^0} \quad (8.1)$$

A univariate polynomial in an indeterminate x is an expression made up of one or more summands of the form $C_k x^k$, which are called monomials. The first factor of each monomial, C_k , is a numerical factor called the **coefficient** where $C_k \in$. The second factor

of each monomial, x^k , is an indeterminate raised to a non-negative integer power i .

Polynomial [4]

Definition 8.8.2 – Degree of the Univariate Polynomial.

$$C_n x^n + C_{n-1} x^{n-1} + \cdots + C_k x^k + \cdots + C_2 x^2 + C_1 x^1 + \underbrace{C_0}_{C_0 x^0}$$

The degree of the univariate polynomial is determined by the monomial with the largest degree of the indeterminate.

9. Simplifying Multivariate Monomials

Definition 9.0.3 – Zero Polynomial. A constant polynomial with a value of zero whose coefficients are all equal to zero is called a zero polynomial. The zero polynomial, 0, can be classified as a degree -1 polynomial. The zero polynomial is the additive identity, AId (4.4b), for polynomials.

[1]

9.1 Simplifying Degree -1 Multivariate Monomials

Example 9.1 – id:20151018-165132.

Simplify $xy - xy$

(S) _____

Solution:

| | |
|--------------|------------|
| $1xy - 1xy$ | MId(4.9a) |
| $1xy + -1xy$ | DOS(4.12a) |
| $(1 + -1)xy$ | DPF(4.3a) |
| $0xy$ | OOA(2.1) |
| 0 | AId(4.4b) |

(D) _____

Dependencies:example 9.7-20151018-164638

■

(R)

This is a special case of a polynomial that is made up of one monomial whose coefficient is equal to zero. This corresponds to a constant with a value of zero and called the zero polynomial 9.0.3. The zero polynomial is the additive identity.

9.2 Simplifying Degree 2 Multivariate Monomials

Example 9.2 – id:20151018-161315.

Simplify by expanding $4x^2y$

(S) _____

Solution:

| | |
|-----------------------------|----------|
| $4 \cdot x \cdot 2 \cdot y$ | JTC(3.5) |
| $4 \cdot 2 \cdot x \cdot y$ | CPM(4.6) |
| $8 \cdot x \cdot y$ | OOM(2.3) |
| $8xy$ | CTJ(3.6) |

9.3 Simplifying Degree 2 Multivariate Binomials

Example 9.3 – id:20151018-164351.

Simplify $10xy + 21xy$

(S) _____

Solution:

| | |
|---------------|-----------|
| $(10 + 21)xy$ | DPF(4.3a) |
| $31xy$ | OOA(2.1) |

(D) _____

Dependencies:example 9.4-20151018-161544

9.4 Simplifying Degree 2 Multivariate Trinomials

Example 9.4 – id:20151018-161544.

Simplify by expanding $(2x + 3y)(7x + 5y)$

(S) _____

Solution:

| | |
|---|-------------------|
| $2x(7x + 5y) + 3y(7x + 5y)$ | DPE(4.8b) |
| $2x \cdot 7x + 2x \cdot 5y + 3y \cdot 7x + 3y \cdot 5y$ | DPE(4.8a) |
| $2 \cdot x \cdot 7 \cdot x + 2 \cdot x \cdot 5 \cdot y + 3 \cdot y \cdot 7 \cdot x + 3 \cdot y \cdot 5 \cdot y$ | JTC(3.5) |
| $2 \cdot 7 \cdot x \cdot x + 2 \cdot 5 \cdot x \cdot y + 3 \cdot 7 \cdot x \cdot y + 3 \cdot 5 \cdot y \cdot y$ | CPM(4.6) |
| $2 \cdot 7 \cdot x^2 + 2 \cdot 5 \cdot x \cdot y + 3 \cdot 7 \cdot x \cdot y + 3 \cdot 5 \cdot y^2$ | PrCBPo(5.3a) |
| $14 \cdot x^2 + 10 \cdot x \cdot y + 21 \cdot x \cdot y + 15 \cdot y^2$ | OOM(2.3) |
| $14x^2 + 10xy + 21xy + 15y^2$ | CTJ(3.6) |
| $14x^2 + 31xy + 15y^2$ | OOA(2.1) goto 9.3 |

Example 9.5 – id:20151018-183900.Simplify by expanding $(x + y)^2$

(S) _____

Solution:

| | |
|---|--|
| $\begin{aligned} & (1x + 1y)^2 \\ & (1x + 1y)(1x + 1y) \\ & 1x(1x + 1y) + 1y(1x + 1y) \\ & 1x \cdot 1x + 1x \cdot 1y + 1y \cdot 1x + 1y \cdot 1y \\ & 1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot 1 \cdot y + 1 \cdot y \cdot 1 \cdot x + 1 \cdot y \cdot 1 \cdot y \\ & 1 \cdot 1 \cdot x \cdot x + 1 \cdot 1 \cdot x \cdot y + 1 \cdot 1 \cdot x \cdot y + 1 \cdot 1 \cdot y \cdot y \\ & 1 \cdot 1 \cdot x^2 + 1 \cdot 1 \cdot x \cdot y + 1 \cdot 1 \cdot x \cdot y + 1 \cdot 1 \cdot y^2 \\ & 1 \cdot x^2 + 1 \cdot x \cdot y + 1 \cdot x \cdot y + 1 \cdot y^2 \\ & 1x^2 + 1xy + 1xy + 1y^2 \\ & 1x^2 + (1 + 1)xy + 1y^2 \\ & 1x^2 + 2xy + 1y^2 \\ & x^2 + 2xy + y^2 \end{aligned}$ | $\text{MId}(4.9\text{a})$ $\text{PoTF}(3.9)$ $\text{DPE}(4.8\text{b})$ $\text{DPE}(4.8\text{a})$ $\text{JTC}(3.5)$ $\text{CPM}(4.6)$ $\text{PrCBPo}(5.3\text{a})$ $\text{OOM}(2.3)$ $\text{CTJ}(3.6)$ $\text{DPF}(4.3\text{a})$ $\text{OOA}(2.1)$ $\text{MId}(4.9\text{b})$ |
|---|--|

Example 9.6 – id:20151018-182202.Simplify by expanding $(x - y)^2$

(S) _____

Solution:

| | |
|---|--------------|
| $(1x - 1y)^2$ | MId(4.9a) |
| $(1x - 1y)(1x - 1y)$ | PoTF(3.9) |
| $(1x - 1y)(1x - 1y)$ | MId(4.9a) |
| $(1x + \neg 1y)(1x + \neg 1y)$ | DOS(4.12a) |
| $1x(1x + \neg 1y) + \neg 1y(1x + \neg 1y)$ | DPE(4.8b) |
| $1x \cdot 1x + 1x \cdot \neg 1y + \neg 1y \cdot 1x + \neg 1y \cdot \neg 1y$ | DPE(4.8a) |
| $1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot \neg 1 \cdot y + \neg 1 \cdot y \cdot 1 \cdot x + \neg 1 \cdot y \cdot \neg 1 \cdot y$ | JTC(3.5) |
| $1 \cdot 1 \cdot x \cdot x + 1 \cdot \neg 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot \neg 1 \cdot y \cdot y$ | CPM(4.6) |
| $1 \cdot 1 \cdot x^2 + 1 \cdot \neg 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot \neg 1 \cdot y^2$ | PrCBPo(5.3a) |
| $1 \cdot x^2 + \neg 1 \cdot x \cdot y + \neg 1 \cdot x \cdot y + 1 \cdot y^2$ | OOM(2.3) |
| $1x^2 + \neg 1xy + \neg 1xy + 1y^2$ | CTJ(3.6) |
| $1x^2 + (\neg 1 + \neg 1)xy + 1y^2$ | DPF(4.3a) |
| $1x^2 + \neg 2xy + 1y^2$ | OOA(2.1) |
| $1x^2 - 2xy + 1y^2$ | DOS(4.12b) |
| $x^2 - 2xy + y^2$ | AId(4.4b) |

Example 9.7 – id:20151018-164638.

Simplify by expanding $(x - y)(x + y)$

S

Solution:

| | |
|---|-------------------|
| $(1x - 1y)(1x + 1y)$ | MId(4.9a) |
| $(1x + \neg 1y)(1x + 1y)$ | DOS(4.12a) |
| $1x(1x + 1y) + \neg 1y(1x + 1y)$ | DPE(4.8b) |
| $1x \cdot 1x + 1x \cdot 1y + \neg 1y \cdot 1x + \neg 1y \cdot 1y$ | DPE(4.8a) |
| $1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot 1 \cdot y + \neg 1 \cdot y \cdot 1 \cdot x + \neg 1 \cdot y \cdot 1 \cdot y$ | JTC(3.5) |
| $1 \cdot 1 \cdot x \cdot x + 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot y \cdot y$ | CPM(4.6) |
| $1 \cdot 1 \cdot x^2 + 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot y^2$ | PrCBPo(5.3a) |
| $1 \cdot x^2 + 1 \cdot x \cdot y + \neg 1 \cdot x \cdot y + \neg 1 \cdot y^2$ | OOM(2.3) |
| $1x^2 + 1xy + \neg 1xy + \neg 1y^2$ | CTJ(3.6) |
| $1x^2 + \neg 1y^2$ | OOA(2.1) goto 9.1 |
| $1x^2 - 1y^2$ | DOS(4.12b) |
| $x^2 - y^2$ | MId(4.9b) |

10. Factoring Univariate Trinomials

Example 10.1 – id:20151015-184212.

Simplify by factoring $x^2 + 7x + 12$

(S) _____

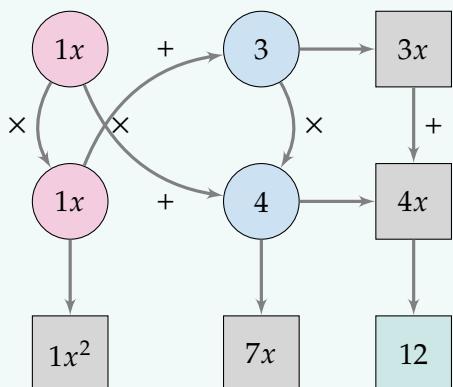
Solution:

Using the distributive property organizer

The factors of $(x^2 + 7x + 12)$ are $(x + 3)(x + 4)$

$$1x^2 + 7x + 12$$

MId(4.9a)



$$(1x + 3)(1x + 4)$$

$$(x + 3)(x + 4)$$

MId(4.9b)

Example 10.2 – id:20151016-063338.

Simplify by factoring $x^2 + x - 2$

(S) _____

Solution:

Using the distributive property organizer

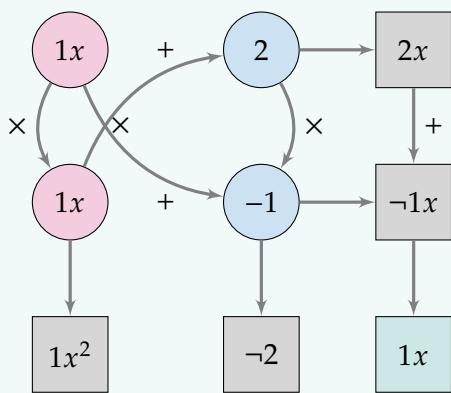
The factors of $(x^2 + x - 2)$ are $(\textcolor{red}{x} + \textcolor{blue}{2})(\textcolor{red}{x} - \textcolor{blue}{1})$

$$1x^2 + 1x - 2$$

AId(4.4a)

$$1x^2 + 1x + \neg 2$$

DOS(4.12a)



$$(1x + 2)(1x + \neg 1)$$

DOS(4.12b)

$$(x + 2)(x - 1)$$

MId(4.9b)

■

11. Solving Linear Equations

11.1 Power Inverse

Example 11.1 – id:20141206-102142.

Solve the equation $x + a = b$ for x

(S) _____

Solution:

$$\begin{array}{ll} [x + a] + \neg a = [b] + \neg a & \text{SPE(4.15)} + \text{AI(4.5a)} \\ x + (a + \neg a) = b + \neg a & \text{APA(4.2b)} \\ x + 0 = b + \neg a & \text{OOA(2.1)} \\ x = b + \neg a & \text{AId(4.4b)} \\ x = b - a & \text{DOS(4.12b)} \end{array}$$

■

Example 11.2 – id:20141111-222931.

Solve the equations $x + 8 = 0$

(S) _____

Solution:

$$\begin{array}{ll} [x + 8] + \neg 8 = [0] + \neg 8 & \text{SPE(4.15)} + \text{AI(4.5a)} \\ x + (8 + \neg 8) = 0 + \neg 8 & \text{APA(4.2b)} \\ x + 0 = \neg 8 & \text{OOA(2.1)} \\ x = \neg 8 & \text{AId(4.4b)} \\ x = -8 & \text{ONeg(3.1b)} \end{array}$$

(S) _____

Less Steps Solution:

$$\begin{array}{ll} [x + 8] + \neg 8 = [0] + \neg 8 & \text{SPE(4.15)} + \text{AI(4.5a)} \\ x = -8 & \text{OOA(2.1)} \end{array}$$

D

Dependencies:
example ??-20141111-190212

Example 11.3 – id:20141206-101632.

Solve the equation $x + 4 = 7$

S

Solution:

$$\begin{array}{ll} [x + 4] + \neg 4 = [7] + \neg 4 & \text{SPE(4.15) + AI(4.5a)} \\ x + (4 + \neg 4) = 7 + \neg 4 & \text{APA(4.2b)} \\ x + 0 = 3 & \text{OOA(2.1)} \\ x = 3 & \text{AId(4.4b)} \end{array}$$

S

Less Steps Solution:

$$\begin{array}{ll} [x] + 4 + \neg 4 = [7] + \neg 4 & \text{SPE(4.15) + AI(4.5a)} \\ x = 3 & \text{OOA(2.1)} \end{array}$$

Example 11.4 – id:20141206-101107.

Solve the equation $x - 8 = 15$ for x

S

Solution:

$$\begin{array}{ll} x + \neg 8 = 15 & \text{DOS(4.12a)} \\ [x + \neg 8] + 8 = [15] + 8 & \text{SPE(4.15) + AI(4.5a)} \\ x + (\neg 8 + 8) = 15 + 8 & \text{APA(4.2b)} \\ x + 0 = 23 & \text{OOA(2.1)} \\ x = 23 & \text{AId(4.4b)} \end{array}$$

S

Less Steps Solution:

$$\begin{aligned} [\mathbf{x} + \mathbf{-8}] + 8 &= [\mathbf{15}] + 8 && \text{SPE(4.15) + AI(4.5a)} \\ x &= 23 && \text{OOA(2.1)} \end{aligned}$$

■

Example 11.5 – id:20141206-102404.

Solve the equation $5x = 9$ for x .

(S)

Solution:

$$\begin{aligned} \frac{1}{5} [\mathbf{5x}] &= \frac{1}{5} [\mathbf{9}] && \text{SPE(4.15) + MI(4.10a)} \\ \frac{1}{5} \cdot [5 \cdot x] &= \frac{1}{5} \cdot 9 && \text{JTC(3.5)} \\ \left(\frac{1}{5} \cdot 5\right) \cdot x &= \frac{1}{5} \cdot 9 && \text{APM(4.7b)} \\ 1 \cdot x &= \frac{9}{5} && \text{OOM(2.3)} \\ x &= \frac{9}{5} && \text{MId(4.9b)} \end{aligned}$$

(S)

Less Steps Solution:

$$\begin{aligned} \frac{1}{5} [\mathbf{5x}] &= \frac{1}{5} [\mathbf{9}] && \text{SPE(4.15) + MI(4.10a)} \\ x &= \frac{9}{5} && \text{OOM(2.3)} \end{aligned}$$

■

Example 11.6 – id:20141206-104404.

Solve the equation $ax = b$ for x .

(S)

Solution:

$$\begin{aligned}\frac{1}{a} [\textcolor{blue}{ax}] &= \frac{1}{a} [\textcolor{blue}{b}] && \text{SPE(4.15) + MI(4.10a)} \\ \frac{1}{a} \cdot (a \cdot x) &= \frac{1}{a} \cdot b && \text{JTC(3.5)} \\ \left(\frac{1}{a} \cdot a\right) \cdot x &= \frac{1}{a} \cdot b && \text{APM(4.7b)} \\ 1 \cdot x &= \frac{b}{a} && \text{OOM(2.3)} \\ x &= \frac{b}{a} && \text{MId(4.9b)}\end{aligned}$$

■

Example 11.7 – id:20141206-102723.Solve the equation $-2x = 7$ for x

(S)

Solution:

$$\begin{aligned}-2x &= 7 && \text{ONeg(3.1a)} \\ -\frac{1}{2} [-2x] &= -\frac{1}{2} [7] && \text{SPE(4.15) + MI(4.10b)} \\ -\frac{1}{2} \cdot (-2 \cdot x) &= -\frac{1}{2} \cdot 7 && \text{JTC(3.5)} \\ \left(-\frac{1}{2} \cdot -2\right) \cdot x &= -\frac{1}{2} \cdot 7 && \text{APM(4.7b)} \\ 1 \cdot x &= -\frac{7}{2} && \text{OOM(2.3)} \\ 1 \cdot x &= -\frac{7}{2} && \text{ONeg(3.1b)} \\ x &= -\frac{7}{2} && \text{MId(4.9b)}\end{aligned}$$

(S)

Less Steps Solution:

$$\begin{aligned}-\frac{1}{2} [-2x] &= -\frac{1}{2} [7] && \text{SPE(4.15) + MI(4.10b)} \\ x &= -\frac{7}{2} && \text{OOM(2.3)}\end{aligned}$$

■

Example 11.8 – id:20141111-215726.

Solve the equation $2x + 5 = 0$ for x

(S) _____

Solution:

$$\begin{aligned}
 [2x + 5] + \neg 5 &= [0] + \neg 5 && \text{SPE(4.15) + AI(4.5a)} \\
 2x + (5 + \neg 5) &= 0 + \neg 5 && \text{APA(4.2a)} \\
 2x + 0 &= \neg 5 && \text{OOA(2.1)} \\
 2x &= \neg 5 && \text{AId(4.4a)} \\
 \frac{1}{2} [2x] &= \frac{1}{2} [\neg 5] && \text{SPE(4.15) + MI(4.10a)} \\
 \frac{1}{2} \cdot 2 \cdot x &= \frac{1}{2} \cdot \neg 5 && \text{JTC(3.5)} \\
 \left(\frac{1}{2} \cdot 2\right) \cdot x &= \frac{1}{2} \cdot \neg 5 && \text{APM(4.7a)} \\
 1 \cdot x &= \frac{\neg 5}{2} && \text{OOM(2.3)} \\
 1x &= -\frac{5}{2} && \text{ONeg(3.1b)} \\
 x &= -\frac{5}{2} && \text{MId(4.9b)}
 \end{aligned}$$

(S) _____

Less Steps Solution:

$$\begin{aligned}
 [2x + 5] + \neg 5 &= [0] + \neg 5 && \text{SPE(4.15) + AI(4.5a)} \quad (11.1) \\
 2x &= \neg 5 && \text{OOA(2.1)} \quad (11.2) \\
 \frac{1}{2} [2x] &= \frac{1}{2} [\neg 5] && \text{SPE(4.15) + MI(4.10a)} \quad (11.3) \\
 x &= -\frac{5}{2} && \text{OOM(2.3)} \quad (11.4)
 \end{aligned}$$

(D) _____

Dependencies:

example ??-20141111-192213

■

Example 11.9 – id:20151015-104754.

Solve the equation $2ax + b = 0$ for x .

(S) _____

Solution:

$$\begin{aligned}
 [2ax + b] + \neg b &= [0] + \neg b && \text{AI(4.5a), SPE(4.15)} \\
 2ax + (b + \neg b) &= 0 + \neg b && \text{APA(4.2b)} \\
 2ax + 0 &= 0 + \neg b && \text{OOA(2.1)} \\
 2ax &= \neg b && \text{AId(4.4a)} \\
 \frac{1}{2a} [2ax] &= \frac{1}{2a} [\neg b] && \text{MI(4.5a), SPE(4.15)} \\
 \frac{1}{2a} \cdot (2ax) &= \frac{1}{2a} \cdot (\neg b) && \text{JTC(3.5)} \\
 \left(\frac{1}{2a} \cdot 2a\right) \cdot x &= \frac{1}{2a} \cdot \neg b && \text{APA(4.2a)} \\
 \left(\frac{1}{2a} \cdot \frac{2a}{1}\right) x &= \frac{1}{2a} \cdot \frac{\text{neg } b}{1} && \text{MId(4.9a)} \\
 \frac{2a}{2a} \cdot x &= \frac{\neg b}{2a} && \text{OOM(2.3)} \\
 1 \cdot x &= \frac{\neg b}{2a} x && = \frac{\neg b}{2a} && \text{MId(4.9b)} \\
 x &= -\frac{b}{2a} && \text{ONeg(3.1b)}
 \end{aligned}$$

(D)

Dependencies:example 18.1-20151008-110208

12. Solving Quadratic Equations

12.1 Mutiliplicative Inverse

Example 12.1 – id:20141107-131748.

Solve the equation $2 - x^2 = 0$ for x

(S) _____

Solution:

| | |
|---|-----------------------|
| $2 - 1x^2 = 0$ | MId(4.9a) |
| $2 + -1x^2 = 0$ | DOS(4.12a) |
| $[2 + -1x^2] + 1x^2 = [0] + 1x^2$ | SPE(4.15) + AI(4.5a) |
| $2 + (-1x^2 + 1x^2) = 0 + 1x^2$ | APA(4.2a) |
| $2 + 0 = 0 + 1x^2$ | OOA(2.1) |
| $2 = 1x^2$ | AId(4.4a) |
| $2 = x^2$ | MId(4.9b) |
| $\pm [2]^{\frac{1}{2}} = [x^2]^{\frac{1}{2}}$ | SPE(4.15) + MI(4.10a) |
| $\pm 2^{\frac{1}{2}} = x$ | PoPo(5.1a) |
| $\pm \sqrt{2} = x$ | PoTR(??) |
| $x = \pm \sqrt{2}$ | SyPE(4.16a) |

■

Example 12.2 – id:20151012-192313.

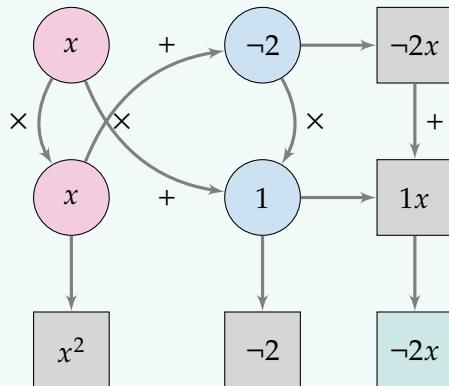
Solve the equation $6x^2 - 6x - 12 = 0$

(S) _____

Solution:

| | |
|------------------------|------------|
| $6x^2 - 6x - 12 = 0$ | DOS(4.12a) |
| $6(1x^2 - 1x - 2) = 0$ | DPF(4.3b) |

Using the factor organizer,



Solving the linear equations using ZPr (4.11a)

$$x_1 + -2 = 0$$

Case I

$$[x_1 + -2] + 2 = [0] + -2$$

AI(4.5a), SPE(4.15)

$$x_1 + (-2 + 2) = 0 + -2$$

APA(4.2a)

$$x_1 + 0 = -2$$

OOA(2.1)

$$x_1 = -2$$

AId(4.4b)

$$x_1 = -2$$

ONeg(3.1b)

$$x_2 + 1 = 0$$

Case II

$$[x_2 + 1] + -1 = [0] + -1$$

AI(4.5a), SPE(4.15)

$$x_2 + (1 + -1) = 0 + -1$$

APA(4.2a)

$$x_2 + 0 = -1$$

OOA(2.1)

$$x_2 = -1$$

AId(4.4b)

$$x_2 = -1$$

ONeg(3.1b)

D

Dependencies:example 17.1-20151012-190708

12.2 Completing The Square

Completing the square is an algebraic process used to find the roots of quadratic equations of the form, $ax^2 + bx + c = 0$. Essentially, we want to manipulate this equation such that $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$.

Proof. Let's begin with a quadratic equation in the general form: $ax^2 + bx + c = 0$. Since we are trying to manipulate the equation $ax^2 + bx + c = 0$ such that $x = \text{some value(s)}$, we first want the coefficient factor a to be equal to 1.

$$\begin{aligned} \frac{1}{a} [ax^2 + bx + c] &= \frac{1}{a} [0] && \text{SPE(4.15) + MI(4.10a)} \\ \frac{1}{a} \cdot ax^2 + \frac{1}{a} \cdot bx + \frac{1}{a} \cdot c &= \frac{1}{a} [0] && \text{DPE(4.8a)} \\ \frac{1}{a} \cdot a \cdot x^2 + \frac{1}{a} \cdot b \cdot x + \frac{1}{a} \cdot c &= \frac{1}{a} [0] && \text{JTC(3.5)} \\ x^2 + \frac{b}{a} \cdot x + \frac{c}{a} &= 0 && \text{OOM(2.3)} \\ x^2 + \frac{b}{a} x + \frac{c}{a} &= 0 && \text{CTJ(3.6)} \end{aligned}$$

We now have three summands in the left hand expression where the first two summands have x^2 and x terms respectively. The goal is to have $x = \text{some value}$, so the next step is focused on removing the $\frac{c}{a}$ summand.

$$\begin{aligned} \left[x^2 + \frac{b}{a} x + \frac{c}{a} \right] + -\frac{c}{a} &= [0] + -\frac{c}{a} && \text{SPE(4.15) + AI(4.5a)} \\ x^2 + \frac{b}{a} x + \left(\frac{c}{a} + -\frac{c}{a} \right) &= 0 + -\frac{c}{a} && \text{APA(4.2a)} \\ x^2 + \frac{b}{a} x + 0 &= -\frac{c}{a} && \text{OOA(2.1)} \\ x^2 + \frac{b}{a} x &= -\frac{c}{a} && \text{AIId(4.4b)} \end{aligned}$$

The next step is called completing the square - the creative step. The idea is to add a *New* constant, k , to the left-hand expression, $x^2 + \frac{b}{a}x + k$, such that the quadratic expression can then be factored as two identical factors, $(x + m)(x + m) = (x + m)^2$, where $k = m \cdot m$.

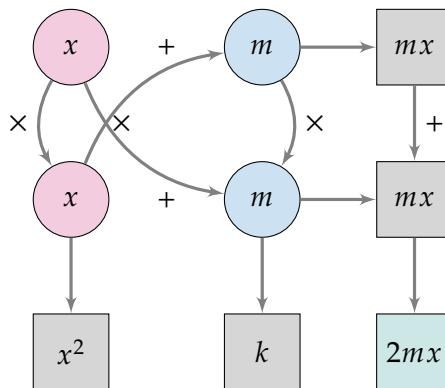


Figure 12.1: The Organization of the Distributive Property

Adding k to the right-hand expression is a consequence of adding k to the left-hand expression to get what we want (a perfect square), $[x^2 + \frac{b}{a}x] + k = [-\frac{c}{a}] + k$.

To determine the values of both m and k we should refer to the the organisation of the two factors, $(x + m)^2$, that make up the product of the quadratic expression, $x^2 + \frac{b}{a}x + k$.

Since both factors of this new quadratic expression are the same, both terms that make up the middle term, must also be the same. We know that $mx + mx = \frac{b}{a}x$, so we should be able to determine the value of m from this equation. If we can determine the value of m , then we can determine the value of k .

$$\begin{aligned}\frac{b}{a}x &= mx + mx \\ &= 2mx\end{aligned}\quad \text{OOA(2.1)}$$

Solving for m ,

$$\begin{aligned}2mx &= \frac{b}{a}x && \text{SPE(4.15) + MI(4.10a)} \\ \frac{1}{2}[2mx] &= \frac{1}{2}\left[\frac{b}{a}x\right] \\ \left(\frac{1}{2} \cdot 2\right)mx &= \left(\frac{1}{2}\frac{b}{a}\right)x && \text{APA(4.2a)} \\ 1mx &= \frac{b}{2a}x && \text{OOM(2.3)} \\ mx &= \frac{b}{2a}x && \text{MId(4.9b)} \\ [mx]\frac{1}{x} &= \left[\frac{b}{2a}x\right]\frac{1}{x} && \text{SPE(4.15) + MI(4.10a)} \\ m\left(x \cdot \frac{1}{x}\right) &= \frac{b}{2a}\left(x \cdot \frac{1}{x}\right) && \text{APM(4.7b)} \\ m \cdot 1 &= \frac{b}{2a} \cdot 1 && \text{OOM(2.3)} \\ m &= \frac{b}{2a} && \text{MId(4.9b)}\end{aligned}$$

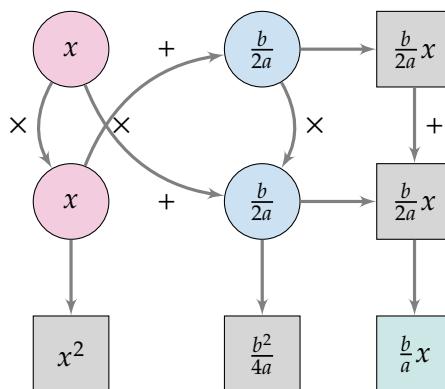


Figure 12.2: The Organization of the Distributive Property

| | |
|---|-----------------------------------|
| $\left[\textcolor{blue}{x^2 + \frac{b}{a}x} \right] + \left(\frac{b}{2a} \right)^2 = \left[-\frac{c}{a} \right] + \left(\frac{b}{2a} \right)^2$ | SPE(4.15) + Completing the Square |
| $x^2 + \frac{b}{a}x + \left(\frac{b}{2a} \right)^2 = -\frac{c}{a} + \left(\frac{b}{2a} \right)^2$ | APA(4.2a) |
| $\left(x + \frac{b}{2a} \right) \left(x + \frac{b}{2a} \right) = -\frac{c}{a} + \left(\frac{b}{2a} \right)^2$ | DPF(4.3b) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{c}{a} + \left(\frac{b}{2a} \right)^2$ | PoTF(3.9) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{c}{a} + \frac{(b)^2}{(2a)^2}$ | PoQPo(5.5a) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{c}{a} + \frac{b^2}{2^2 a^2}$ | PoPrPo(5.6a) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{c}{a} + \frac{b^2}{4a^2}$ | OOE(2.5) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{c}{a} \cdot \frac{\textcolor{red}{4a}}{\textcolor{red}{4a}} + \frac{b^2}{4a^2}$ | MId(4.9a) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{c \cdot 4 \cdot a}{a \cdot 4 \cdot a} + \frac{b^2}{4a^2}$ | JTC(3.5) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{4 \cdot a \cdot c}{4 \cdot a \cdot a} + \frac{b^2}{4a^2}$ | CPM(4.6) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{4 \cdot a \cdot c}{4 \cdot a^2} + \frac{b^2}{4a^2}$ | PrCBPo(5.3a) |
| $\left(x + \frac{b}{2a} \right)^2 = -\frac{4ac}{4a^2} + \frac{b^2}{4a^2}$ | CTJ(3.6) |
| $\left(x + \frac{b}{2a} \right)^2 = \frac{-4ac + b^2}{4a^2}$ | CD(2.6a) |
| $\left(x + \frac{b}{2a} \right)^2 = \frac{b^2 - 4ac}{4a^2}$ | CPM(4.6) |
| $\left[\left(x + \frac{b}{2a} \right)^2 \right]^{\frac{1}{2}} = \pm \left[\frac{\textcolor{blue}{b^2 - 4ac}}{4a^2} \right]^{\frac{1}{2}}$ | SPE(4.15) |
| $x + \frac{b}{2a} = \pm \left[\frac{b^2 - 4ac}{4a^2} \right]^{\frac{1}{2}}$ | PoPrPo(5.6a) |
| $x + \frac{b}{2a} = \pm \frac{\left[b^2 - 4ac \right]^{\frac{1}{2}}}{[4a^2]^{\frac{1}{2}}}$ | PoQPo(5.5a) |
| $x + \frac{b}{2a} = \pm \frac{\left[b^2 - 4ac \right]^{\frac{1}{2}}}{4^{\frac{1}{2}} a}$ | PoPrPo(5.6a) |
| $x + \frac{b}{2a} = \pm \frac{\left[b^2 - 4ac \right]^{\frac{1}{2}}}{2a}$ | OOE(2.5) |
| $x + \frac{b}{2a} = \pm \frac{\sqrt{b^2 - 4ac}}{2a}$ | RTPo(3.12) |

$$\begin{aligned}
 \left[x + \frac{b}{2a} \right] + -\frac{b}{2a} &= \left[\pm \frac{\sqrt{b^2 - 4ac}}{2a} \right] + -\frac{b}{2a} && \text{SPE(4.15) + AI(4.5a)} \\
 x + \left(\frac{b}{2a} + -\frac{b}{2a} \right) &= \pm \frac{\sqrt{b^2 - 4ac}}{2a} + -\frac{b}{2a} && \text{APA(4.2b)} \\
 x + \left(\frac{b}{2a} + -\frac{b}{2a} \right) &= -\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a} && \text{CPM(4.6)} \\
 x + 0 &= -\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a} && \text{OOA(2.1)} \\
 x &= -\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a} && \text{AId(4.4b)} \\
 x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} && \text{CD(2.6a)} \\
 x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} && \text{DOS(4.12b)} \\
 x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} && \text{ONeg(3.1b)}
 \end{aligned}$$

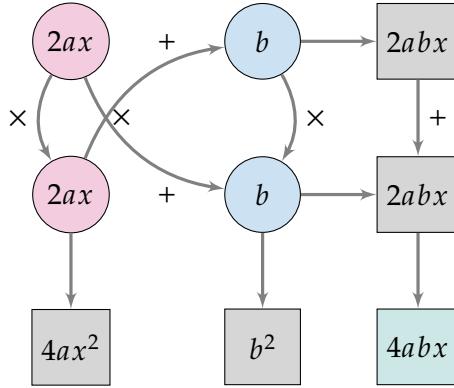
■

The previous proof starts with choosing to multiply both expressions by the multiplicative inverse of the coefficient of the degree two term such that ax^2 becomes x^2 . It is easier to manually complete the square, guess the two binomial factors, when the coefficient of the degree 2 term is 1. However, as a consequence, the coefficients of the degree one and degree zero terms become fractions $\frac{b}{a}$ and $\frac{c}{a}$ respectively. All that it means is that we have to work with fractions throughout the procedure.

Proof.

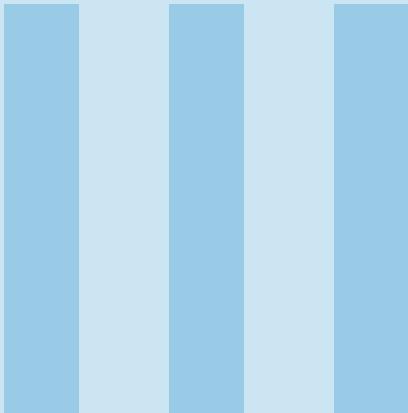
$$\begin{aligned}
 ax^2 + bx + c &= 0 \\
 4a [ax^2 + bx + c] &= 4a [0] && \text{SPE(4.15)} \\
 4ax^2 + 4abx + 4ac &= 4a(0) && \text{DPE(4.8a)} \\
 4ax^2 + 4abx + 4ac &= 0 && \text{OOM(2.3)} \\
 [4ax^2 + 4abx + 4ac] + -4ac &= [0] + -4ac && \text{AI(4.5a), SPE(4.15)} \\
 4ax^2 + 4abx + (4ac + -4ac) &= 0 + -4ac && \text{APA(4.2a)} \\
 4ax^2 + 4abx + 0 &= 0 + -4ac && \text{OOA(2.1)} \\
 4ax^2 + 4abx &= -4ac && \text{AId(4.4b)}
 \end{aligned}$$

Completing the square



| | |
|---|---------------------|
| $[4ax^2 + 4abx] + b^2 = [-4ac] + b^2$ | SPE(4.15) |
| $4ax^2 + 4abx + b^2 = b^2 + -4ac$ | CPA(4.1) |
| $(2ax + b)(2ax + b) = b^2 + -4ac$ | DPF(4.3a) |
| $(2ax + b)^2 = b^2 + -4ac$ | PoTF(3.9) |
| $[(2ax + b)^2]^{\frac{1}{2}} = \pm [b^2 + -4ac]^{\frac{1}{2}}$ | SPE(4.15) |
| $2ax + b = \pm(b^2 + -4ac)^{\frac{1}{2}}$ | PoPo(5.1a) |
| $2ax + b = \pm\sqrt{b^2 + -4ac}$ | PoTR(??) |
| $[2ax + b] + -b = [\pm\sqrt{b^2 + -4ac}] + -b$ | AI(4.5a), SPE(4.15) |
| $(2ax + b) + -b = -b \pm \sqrt{b^2 + -4ac}$ | CPA(4.1) |
| $2ax + (b + -b) = -b \pm \sqrt{b^2 + -4ac}$ | APA(4.2b) |
| $2ax + 0 = -b \pm \sqrt{b^2 + -4ac}$ | OOA(2.1) |
| $2ax = -b \pm \sqrt{b^2 + -4ac}$ | AId(4.4b) |
| $\frac{1}{2a} [2ax] = \frac{1}{2a} [\pm\sqrt{b^2 + -4ac}]$ | MI(4.5a), SPE(4.15) |
| $\left(\frac{1}{2a} \cdot 2a\right)x = \frac{1}{2a} (-b \pm \sqrt{b^2 + -4ac})$ | APM(4.7a) |
| $\frac{2a}{2a}x = \frac{-b \pm \sqrt{b^2 + -4ac}}{2a}$ | OOM(2.3) |
| $1x = \frac{-b \pm \sqrt{b^2 + -4ac}}{2a}$ | RF(??) |
| $1x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ | DOS(4.12b) |
| $1x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ | ONeg(3.1b) |
| $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ | MId(4.9b) |

■



Functions

13. Functions

Property 13.0.1 – Function Value Argument Substitution (FVAS).

$$f(a) \quad (13.1a)$$

Example 13.1 – id:20151012-201647.

Find $f(2)$ given $f(x) = 2x^3 - 3x^2 - 12x + 1$

(S) _____

Solution:

$$f(x) = 2x^3 + -3x^2 + -12x + 1 \quad \text{DOS}(4.12a)$$

$$f(2) = 2[2]^3 + -3[2]^2 + -12[2] + 1 \quad \text{SPE}(4.15)$$

$$f(2) = 2(8) + -3(4) + -12(2) + 1 \quad \text{OOE}(2.5)$$

$$f(2) = 16 + -12 + -24 + 1 \quad \text{OOM}(2.3)$$

$$f(2) = -19 \quad \text{OOA}(2.1)$$

(D) _____

Dependencies:example 17.1-20151012-190708

Example 13.2 – id:20151012-203549.

Find $f(-1)$ given $f(x) = 2x^3 - 3x^2 - 12x + 1$

(S) _____

Solution:

$$f(x) = 2x^3 + -3x^2 + -12x + 1 \quad \text{DOS(4.12a)}$$

$$f(-1) = 2[-1]^3 + -3[-1]^2 + -12[-1] + 1 \quad \text{SPE(4.15)}$$

$$f(-1) = 2(-1) + -3(1) + -12(-1) + 1 \quad \text{OOE(2.5)}$$

$$f(-1) = -2 + -3 + 12 + 1 \quad \text{OOM(2.3)}$$

$$f(-1) = 8 \quad \text{OOA(2.1)}$$

(D) _____

Dependencies:example 17.1-20151012-190708

■

13.1 Inverse Functions

13.2 Inverses

Property 13.2.1 – Cosine Inverse (ArcCos).

$$\cos^{-1}(\cos \theta) = \theta \quad (13.2a)$$

Property 13.2.2 – Sine Inverse (ArcSin).

$$\sin^{-1}(\sin \theta) = \theta \quad (13.3a)$$

Property 13.2.3 – Tangent Inverse (ArcTan).

$$\tan^{-1}(\tan \theta) = \theta \quad (13.4a)$$

Property 13.2.4 – Exponential Inverse (EI).

$$\log_a(a^x) = x \quad (13.5a)$$

Property 13.2.5 – Logarithmic Inverse (LI).

$$a^{\log_a x} = x \quad (13.6a)$$

Property 13.2.6 – Power Inverse (Pol).

$$(b^m)^{\frac{1}{m}} = b \quad (13.7a)$$

Differential Calculus

| | | |
|-----------|--|------------|
| 14 | Derivative by First Principles | 87 |
| 14.1 | Limit of the Difference Quotient | |
| 15 | Derivative Rules | 89 |
| 15.1 | Derivative of a Monomial Functions | |
| 15.2 | Derivative of Polynomial Functions | |
| 15.3 | Derivative of a Quotient | |
| 15.4 | Derivative of a Rational Function | |
| 16 | Equations of Tangent & Secant Lines | 99 |
| 16.1 | Essential Questions | |
| 16.2 | Finding the Equation of the Tangent Line | |
| 17 | First Derivative Test | 103 |
| 18 | Curve Sketching | 105 |
| 19 | Second Derivative Test | 107 |
| 20 | Curve Sketching | 109 |
| | Bibliography | 111 |
| | Bibliography | 111 |
| | Websites | |
| | Articles | |
| | Index | 113 |

14. Derivative by First Principles

14.1 Limit of the Difference Quotient

Definition 14.1.1 – Derivative. The derivative of a function $f(x)$ with respect to the variable x is defined as

$$f'(x) \equiv \lim_{\Delta x \rightarrow 0} \underbrace{\frac{f(x + \Delta x) - f(x)}{\Delta x}}_{\text{Difference Quotient}} \quad (14.1)$$

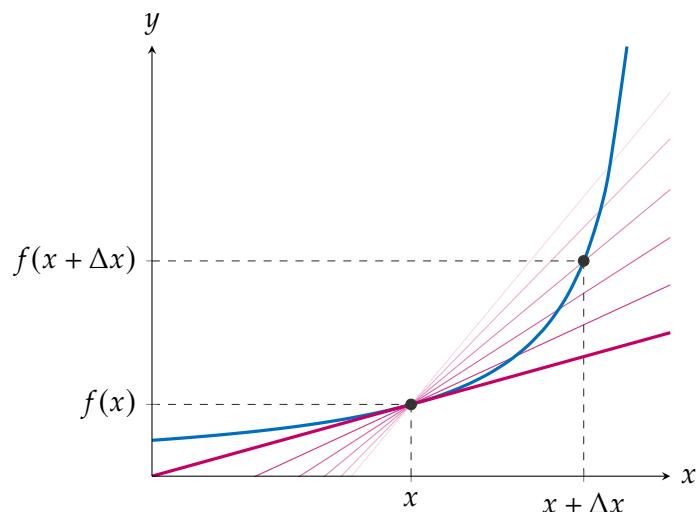


Figure 14.1: [3]

Example 14.1 – id:20141219-212546.

Differentiate the function $f(x) = 5$

(S)

Solution:

$$f(x) = 5x^0 \quad \text{PoID(4.13a)}$$

$$f'(x) = \lim_{\Delta x \rightarrow 0} \frac{5[x + \Delta x]^0 - 5[x]^0}{\Delta x} \quad \text{SPE(4.15) \& DBFP(14.1)}$$

$$f'(x) = \lim_{\Delta x \rightarrow 0} \frac{5(1) - 5(1)}{\Delta x} \quad \text{PoID(4.13b)}$$

$$f'(x) = \lim_{\Delta x \rightarrow 0} 0 \quad \text{OOM(2.3)}$$

$$f'(x) = 0$$

■

15. Derivative Rules

15.1 Derivative of a Monomial Functions

Example 15.1 – id:20141124-153017.

Differentiate $f(x) = -3$

(S) _____

Solution:

$$f'(x) = [-3]'$$

SPE(4.15)

$$f'(x) = 0$$

DC(7.1)

(D) _____

Dependencies:

example 15.3-20141124-152503

■

Example 15.2 – id:20141124-141850.

Differentiate $f(x) = x^2$

(S) _____

Solution:

$$f'(x) = [x^2]'$$

SPE(4.15)

$$f'(x) = 2x^{2-1}$$

DPo(7.5)

$$f'(x) = 2x^1$$

OOA(2.1)

$$f'(x) = 2x$$

MId(4.9b)

(S) _____

Less Steps Solution:

$$f'(x) = 2x$$

DPo(7.5)

(D) _____

Dependencies:

example 15.2-20141124-141850

example 15.3-20141124-152503

■

15.2 Derivative of Polynomial Functions**Example 15.3 – id:20141124-152503.**Differentiate $f(x) = x^2 - 3$

(S) _____

Solution:

$$f(x) = x^2 + -3 \quad \text{DOS(4.12a)}$$

$$f'(x) = [x^2 + -3]' \quad \text{SPE(4.15)}$$

$$f'(x) = [x^2]' + [-3]' \quad \text{DS(7.7)}$$

$$f'(x) = [x^2]' + 0 \quad \text{DC(7.1)}$$

$$f'(x) = [x^2]' \quad \text{AId(4.4a)}$$

$$f'(x) = 2x \quad \text{DPo(7.5) goto 15.2}$$

(S) _____

Less Steps Solution:

$$f(x) = 2x^2 \quad \text{DPo(7.5)&DC(7.5)}$$

(D) _____

Dependencies:

example 15.14-20141124-205219

■

Example 15.4 – id:20151015-155838.Differentiate $y = x^3 + 1$

(S) _____

Solution:

$$\begin{aligned} [\textcolor{blue}{y}]' &= [\textcolor{blue}{x^3 + 1}] && \text{SPE(4.15)} \\ y' &= [x^3]' + [1]' && \text{DS(7.7)} \\ y' &= 3x^2 + [1]' && \text{DPo(7.5)} \\ y' &= 3x^2 + 0 && \text{DC(7.1)} \\ y' &= 3x^2 && \text{MId(4.9b)} \end{aligned}$$

(D) _____

Dependencies:example 15.16-20151015-153507

■

Example 15.5 – id:20151011-195002.

Differentiate $f(x) = 2x^2 + 3x + 7$

(S) _____

Solution:

$$\begin{aligned} [\textcolor{blue}{f'(x)}]' &= [\textcolor{blue}{2x^2 + 3x + 7}]' && \text{SPE(4.15)} \\ f'(x) &= [\textcolor{blue}{2x^2}]' + [\textcolor{blue}{3x}]' + [\textcolor{blue}{7}]' && \text{DS(7.7)} \\ f'(x) &= 2[\textcolor{blue}{x^2}]' + 3[\textcolor{blue}{x}]' + [\textcolor{blue}{7}]' && \text{DCM(7.3)} \\ f'(x) &= 2[\textcolor{blue}{x^2}]' + 3[\textcolor{blue}{x}]' + 0 && \text{DC(7.1)} \\ f'(x) &= 2[\textcolor{blue}{x^2}]' + 3[\textcolor{blue}{x}]' && \text{AId(4.4a)} \\ f'(x) &= 2(2x) + 3 && \text{DPo(7.5)} \\ f'(x) &= 4x + 3 && \text{OOM(2.3)} \end{aligned}$$

(D) _____

Dependencies:example 16.1-20151011-154209

■

Example 15.6 – id:20141128-151834.

Differentiate $f(x) = 3x^2 - 6x + 4$

(S) _____

Solution:

$$f(x) = 3x^2 + \neg 6x + 4 \quad \text{DOS(4.12a)}$$

$$f'(x) = [3x^2 + \neg 6x + 4]' \quad \text{SPE(4.15)}$$

$$f'(x) = [3x^2]' + [6x]' + [4]' \quad \text{DS(7.7)}$$

$$f'(x) = [3x^2]' + [6x]' + 0 \quad \text{DC(7.1)}$$

$$f'(x) = [3x^2]' + [6x]' \quad \text{AId(4.4a)}$$

$$f'(x) = 3[x^2]' + 6[x]' \quad \text{DCM(7.3)}$$

$$f'(x) = 3(2x) + 6(1) \quad \text{DPo(7.5)}$$

$$f'(x) = 6x + 6 \quad \text{OOM(2.3)}$$

(S)

$$f'(x) = 6x + 6 \quad \text{DS(7.7)}$$

■

Example 15.7 – id:20141209-144203.

Differentiate $f(x) = x^2(2x + 4)$

(S)

Solution:

$$f'(x) = [x^2(2x + 4)]' \quad \text{SPE(4.15)}$$

$$f'(x) = [x^2]'(2x + 4) + x^2[2x + 4]' \quad \text{DPr(7.11)}$$

$$f'(x) = [x^2]'(2x + 4) + x^2[2x] + [4]' \quad \text{DS(7.7)}$$

$$f'(x) = [x^2]'(2x + 4) + x^2 \cdot 2[x] + [4]' \quad \text{DCM(7.3)}$$

$$f'(x) = 2x(2x + 4) + x^2 \cdot 2 \cdot 1 + [4]' \quad \text{DPo(7.5)}$$

$$f'(x) = 2x(2x + 4) + x^2 \cdot 2 \cdot 1 + 0 \quad \text{DC(7.1)}$$

$$f'(x) = 6x^2 + 8x \quad \text{simplify goto 8.34}$$

■

Example 15.8 – id:20141209-142321.

Differentiate $f(x) = x^2 \cos(x)$

(S)

Solution:

$$\begin{aligned} f'(x) &= [\mathbf{x^2 \cos(x)}]' && \text{SPE(4.15)} \\ f'(x) &= [\mathbf{x^2}]' \cos(x) + x^2 [\mathbf{\cos(x)}]' && \text{DPr(7.11)} \\ f'(x) &= 2x \cos(x) + x^2 [\mathbf{\cos(x)}]' && \text{DPo(7.5)} \\ f'(x) &= 2x \cos(x) + x^2(-1 \sin(x)) && \text{DCos(7.19)} \\ f'(x) &= 2x \cos(x) - x^2 \sin x && \text{OOM(2.3)} \end{aligned}$$

■

Example 15.9 – id:20150910-115935.Differentiate $f(x) = \sin(x) \cos(x)$

(S)

Solution:

$$\begin{aligned} f'(x) &= [\mathbf{\sin(x) \cos(x)}]' && \text{SPE(4.15)} \\ f'(x) &= [\mathbf{\sin(x)}]' \cos(x) + \sin(x) [\mathbf{\cos(x)}]' && \text{DPr(7.11)} \\ f'(x) &= \cos(x) \cos(x) + \sin(x) [\mathbf{\cos(x)}]' && \text{DSin(7.17)} \\ f'(x) &= \cos(x) \cos(x) + \sin(x)(-\sin(x)) && \text{DCos(7.19)} \\ f'(x) &= \cos^2(x) - \sin^2(x) && \text{simplify goto ??} \end{aligned}$$

■

Example 15.10 – id:20141209-151354.Differentiate $f(x) = \sin(x) \sin(x)$

(S)

Solution:

$$\begin{aligned} f'(x) &= [\mathbf{\sin(x) \sin(x)}]' && \text{SPE(4.15)} \\ f'(x) &= [\mathbf{\sin(x)}]' \sin(x) + \sin(x) [\mathbf{\sin(x)}] && \text{DPr(7.11)} \\ f'(x) &= \cos(x) \sin(x) + \sin(x) \cos(x) && \text{DSin(7.17)} \\ f'(x) &= \cos(x) \sin(x) + \cos(x) \sin(x) && \text{CPM(4.6)} \\ f'(x) &= 2 \cos(x) \sin(x) && \text{OOA(2.1)} \end{aligned}$$

■

Example 15.11 – id:20141124-203850.Differentiate $y = \ln(3x)$

(S)

Solution:

After identifying that $y = \ln(3x)$ is a composite function, we let $u = 3x$ and thus we get a new function $y = \ln(u)$.

Using chain rule,

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \quad \text{DComp(7.16)}$$

We need to find the factors $\frac{dy}{du}$ and $\frac{du}{dx}$.

$$y = \ln(u) \quad u = 3x$$

$$\frac{dy}{du} = \frac{1}{u} \quad \frac{du}{dx} = 3$$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \quad \text{DComp(7.16)}$$

$$\frac{dy}{dx} = \frac{1}{u} \cdot \frac{du}{dx} \quad \text{DNL(7.31)}$$

$$\frac{dy}{dx} = \frac{1}{u} \cdot 3 \quad \text{DPo(7.5)}$$

$$\frac{dy}{dx} = \frac{1}{3x} \cdot 3$$

$$\frac{dy}{dx} = \frac{3}{3x} \quad \text{OOM(2.3)}$$

$$\frac{dy}{dx} = \frac{1}{x}$$

(D)

Dependencies:

example 15.14-20141124-205219

Example 15.12 – id:20141128-160248.

Differentiate $y = \ln(3x^2 - 6x + 4)$

(S)

Solution: After identifying that $y = \ln(3x^2 - 6x + 4)$ is a composite function, we let $u = 3x^2 - 6x + 4$ and thus we get a new function $y = \ln(u)$.

Using chain rule,

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \quad \text{DComp(7.16)}$$

We need to find the factors $\frac{dy}{du}$ and $\frac{du}{dx}$.

$$y = \ln(u) \quad u = 3x^2 - 6x + 4$$

$$\frac{dy}{du} = \frac{1}{u} \quad \frac{du}{dx} = 6x - 6 \quad \text{goto 15.6}$$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \quad \text{DComp(7.16)}$$

$$\frac{dy}{dx} = \frac{1}{u} \cdot \frac{du}{dx} \quad \text{DNL(7.31)}$$

$$\frac{dy}{dx} = \frac{1}{u} \cdot (6x - 6) \quad \text{DPo(7.5)}$$

$$\frac{dy}{dx} = \frac{1}{3x^2 - 6x + 4} \cdot (6x - 6)$$

$$\frac{dy}{dx} = \frac{6x - 6}{3x^2 - 6x + 4} \quad \text{OOM(2.3)}$$

Example 15.13 – id:20141128-155506.

Differentiate $y = \ln(\cos x)$

(S)

Solution: After identifying that $y = \ln(\cos x)$ is a composite function, we let $u = \cos x$ and thus we get a new function $y = \ln(u)$.

Using chain rule,

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \quad \text{DComp(7.16)}$$

We need to find the factors $\frac{dy}{du}$ and $\frac{du}{dx}$.

$$y = \ln(u) \quad u = \cos x$$

$$\frac{dy}{du} = \frac{1}{u} \quad \frac{du}{dx} = -\sin x$$

$$\begin{aligned}\frac{dy}{dx} &= \frac{\text{d}y}{\text{d}u} \cdot \frac{\text{d}u}{\text{d}x} && \text{DComp(7.16)} \\ \frac{dy}{dx} &= \frac{1}{u} \cdot \frac{\text{d}u}{\text{d}x} && \text{DNL(7.31)} \\ \frac{dy}{dx} &= \frac{1}{u} \cdot -\sin x && \text{DPo(7.5)} \\ \frac{dy}{dx} &= \frac{1}{\cos x} \cdot -\sin x \\ \frac{dy}{dx} &= \frac{-\sin x}{\cos x} && \text{OOM(2.3)} \\ \frac{dy}{dx} &= -\tan x\end{aligned}$$

■

Example 15.14 – id:20141124-205219.Differentiate $y = (x^2 - 1) \ln(3x)$

(S)

Solution:

$$\begin{aligned}y' &= [x^2 - 3]' \cdot \ln x + (x^2 - 3) \cdot [\ln 3x]' && \text{DPr(7.11)} \\ y' &= 2x \cdot \ln x + (x^2 - 3) \cdot [\ln 3x]' && \text{differentiate goto 15.3} \\ y' &= 2x \cdot \ln x + (x^2 - 3) \cdot \frac{1}{x} && \text{differentiate goto 15.11} \\ y' &= 2x \cdot \ln x + \frac{x^2 - 3}{x} && \text{OOM(2.3)} \\ y' &= 2x^2 \ln x + \frac{x^2 - 3}{x} && \text{JTC(3.5)} \\ y' &= \frac{2x^2 \ln x + (x^2 - 3)}{x} && \text{OOA(2.1)}\end{aligned}$$

■

15.3 Derivative of a Quotient**Example 15.15 – id:20151015-165037.**Differentiate $y = \frac{\sin x}{e^x}$

(S)

Solution:

$$\frac{d[y]}{dx} = \frac{d\left[\frac{\sin x}{e^x}\right]}{dx} \quad \text{SPE(4.15)}$$

$$\frac{dy}{dx} = \frac{\frac{d}{dx} [\sin x] e^x - \sin x \frac{d}{dx} [e^x]}{[e^x]^2} \quad \text{DQ(??)}$$

$$\frac{dy}{dx} = \frac{\frac{d}{dx} [\sin x] e^x - \sin x \frac{d}{dx} [e^x]}{e^{2x}} \quad \text{PoPo(5.1a)}$$

$$\frac{dy}{dx} = \frac{\cos x e^x - \sin x \frac{d}{dx} [e^x]}{e^{2x}} \quad \text{DSin(7.18)}$$

$$\frac{dy}{dx} = \frac{\cos x e^x - \sin x e^x}{e^{2x}} \quad \text{DExp(7.34)}$$

$$\frac{dy}{dx} = \frac{e^x(\cos x - \sin x)}{e^{2x}} \quad \text{DPF(4.3b)}$$

$$\frac{dy}{dx} = \frac{e^x(\cos x - \sin x)}{e^x e^x} \quad \text{PrCBPo(5.3b)}$$

$$\frac{dy}{dx} = \frac{e^x(\cos x - \sin x)}{e^x e^x} \quad \text{MId(4.9a)}$$

$$\frac{dy}{dx} = \frac{\cos x - \sin x}{e^x}$$

■

15.4 Derivative of a Rational Function

Example 15.16 – id:20151015-153507.Differentiate $f(x) = \frac{x^3 + 1}{x^2}$

(S)

Solution:

Method 1: Derivative of a quotient

$$[f(x)]' = \left[\frac{x^3 + 1}{x^2} \right]' \quad \text{SPE(4.15)}$$

$$f'(x) = \frac{[x^3 + 1]'(x^2) + -1((x^3 + 1)[x^2]')}{[x^2]^2} \quad \text{DQ(??)}$$

$$f'(x) = \frac{(3x^2)(x^2) - 1((x^3 + 1)[x^2]')}{[x^2]^2} \quad \text{differentiate goto 15.4}$$

$$f'(x) = \frac{(3x^2)(x^2) - 1((x^3 + 1)(2x))}{[x^2]^2} \quad \text{differentiate goto 15.2}$$

$$f'(x) = \frac{3x^3 - 2x^2 - 2}{x^3} \quad \text{Simplify goto ??}$$

■

16. Equations of Tangent & Secant Lines

16.1 Essential Questions

Essential Questions 16.1

1. How do we find the equation of the tangent line of a given function at the point $P(a, b)$?
2. How do we find the equation of the tangent line of a given function at $x = a$?

16.2 Finding the Equation of the Tangent Line

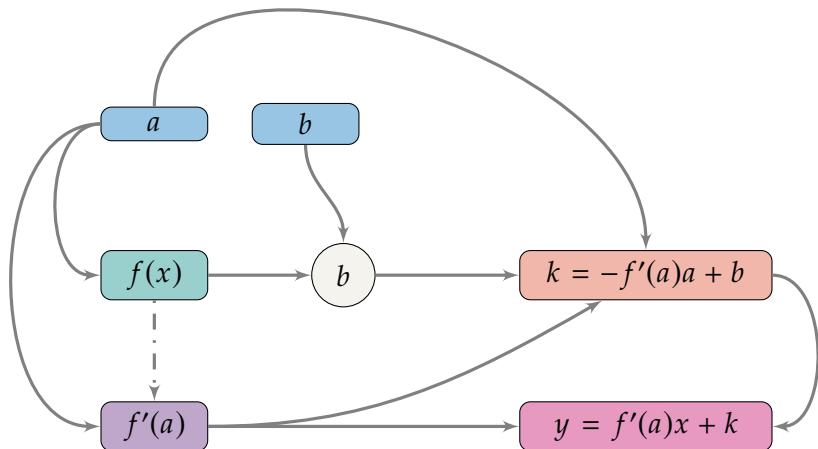


Figure 16.1: Finding the Equation of a Tangent Line Workflow

For a given function, $f(x)$, our goal is to find the equation of the tangent line at the point $P(a, b)$, which can be expressed in slope-intercept form as:

$$y = f'(a)x + k$$

Where $f'(a)$ is the value of the derivative, slope, at $x = a$ and k is the y -intercept. We therefore need to:

1. Find the derivative of the function $f(x)$: $f'(x)$
2. Find the value of the derivative at $x = a$: $f'(a)$
3. Find the value of the y -intercept: $k = -f'(a) + b$:
4. If the ordinate b is not explicitly given, then find $f(a) = b$

Example 16.1 – id:20151011-154209.

Find the equation of the line tangent to the curve of the function $f(x) = 2x^2 + 3x + 7$ at the point $P(2, 21)$.

(S) _____

Solution:

Find the derivative of $f(x)$

$$f'(x) = 4x + 3 \text{ goto 15.5}$$

Evaluate the derivative at $x = 2$

$$f'(2) = 4[2] + 3$$

SPE(4.15)

$$f'(2) = 8 + 3$$

OOM(2.3)

$$f'(2) = 11$$

OOA(2.1)

Find the y -intercept, k , of the equation of the tangent line.

$$y = f'(x)x + k$$

$$[21] = [11][2] + k \quad \text{SPE(4.15)}$$

$$21 = 22 + k$$

OOM(2.3)

$$\neg 22 + [21] = \neg 22 + [22 + k]$$

SPE+AI

$$\neg 22 + 21 = (\neg 22 + 22) + k$$

APA(4.2a)

$$\neg 1 = 0 + k$$

OOA(2.1)

$$\neg 1 = k$$

AId(4.4a)

$$\neg 1 = k$$

ONeg(3.1b)

$$k = -1$$

SyPE(4.16a)

The equation of the tangent line is

$$y = f'(2)x + k$$

$$y = 11x - 1 \quad \text{SPE(4.15)}$$

Example 16.2 – id:20151015-171630.

Given $f(x) = e^{3x}$, find the the equation of the tangent line L to the curve f at the point $(2, e^2)$.

(S) _____

Solution:

Find the derivative of $f(x)$

$$\begin{aligned}
 [f(x)]' &= [e^{3x}]' && \text{SPE(4.15)} \\
 f'(x) &= [3x]'[e^{3x}]' && \text{DCF(7.15)} \\
 f'(x) &= 3[x]'[e^{3x}]' && \text{DCM(7.3)} \\
 f'(x) &= 3 \cdot 1[e^{3x}]' && \text{DPo(7.5)} \\
 f'(x) &= 3[e^{3x}]' && \text{OOM(2.3)} \\
 f'(x) &= 3e^{3x} && \text{DExp(7.33)}
 \end{aligned}$$

Evaluate the derivative at $x = 2$

$$\begin{aligned}
 f'(2) &= 3e^{3[2]} && \text{SPE(4.15)} \\
 f'(2) &= 3e^6 && \text{OOM(2.3)}
 \end{aligned}$$

Find the y -intercept, k , of the equation of the tangent line.

$$\begin{aligned}
 y &= f'(x)x + k \\
 [e^2] &= [3e^6][2] + k && \text{SPE(4.15)} \\
 e^2 &= 3 \cdot e^6 \cdot 2 + k && \text{JTC(3.5)} \\
 e^2 &= 3 \cdot 2 \cdot e^6 + k && \text{CPM(4.6)} \\
 e^2 &= 6 \cdot e^6 + k && \text{OOM(2.3)} \\
 e^2 &= 6e^6 + k && \text{CTJ(3.6)} \\
 -6e^6 + [e^2] &= -6e^6 + [6e^6 + k] && \text{AI(4.5a), SPE(4.15)} \\
 e^2(-6e^4 + 1) &= -6e^6 + [6e^6 + k] && \text{DPF(4.3b)} \\
 -6e^6 + e^2 &= (-6e^6 + 6e^6) + k && \text{APA(4.2a)} \\
 e^2(-6e^4 + 1) &= 0 + k && \text{OOA(2.1)} \\
 e^2(-6e^4 + 1) &= k && \text{AId(4.4b)} \\
 e^2(-6e^4 + 1) &= k && \text{ONeg(3.1b)}
 \end{aligned}$$

The equation of the tangent line, L is

$$\begin{aligned}
 y &= f'(2)x + k \\
 y &= 3e^6x + e^2(-6e^4 + 1) && \text{SPE(4.15)}
 \end{aligned}$$

17. First Derivative Test

Example 17.1 – id:20151012-190708.

Given the function $f(x) = 2x^3 - 3x^2 - 12x + 1$ find the critical points, classify the critical points and find the intervals of increasing/decreasing.

(S)

Solution:

Differentiate the function:

$$f(x) = 2x^3 - 3x^2 - 12x + 1 \quad \text{DOS(4.12a)}$$

$$[f(x)]' = [2x^3 + -3x^2 + -12x + 1]' \quad \text{SPE(4.15)}$$

$$f'(x) = [2x^3]' + [-3x^2]' + [-12x]' + [1]' \quad \text{DS(7.7)}$$

$$f'(x) = 2[x^3]' + -3[x^2]' + -12[x]' + [1]' \quad \text{DCM(7.3)}$$

$$f'(x) = 2(3x^2) + -3(2x) + -12(1) + [1]' \quad \text{DPo(7.5)}$$

$$f'(x) = 6x^2 + -6x + -12 + [1]' \quad \text{OOM(2.3)}$$

$$f'(x) = 6x^2 + -6x + -12 + 0 \quad \text{DC(7.1)}$$

$$f'(x) = 6x^2 + -6x + -12 \quad \text{AId(4.4a)}$$

Solving the equation $6x^2 + -6x + -12 = 0$ to find the x value(s) of the critical points, goto 12.2, we find that $x = 2$ and $x = -1$ are critical values of the function.

Since we are looking for critical **points**, we need to find the ordinates, y -values, of the critical points by evaluating the function for the given critical x -values.

$$f(2) = -19 \text{ goto 13.1}$$

$$f(-1) = 8 \text{ goto 13.2}$$

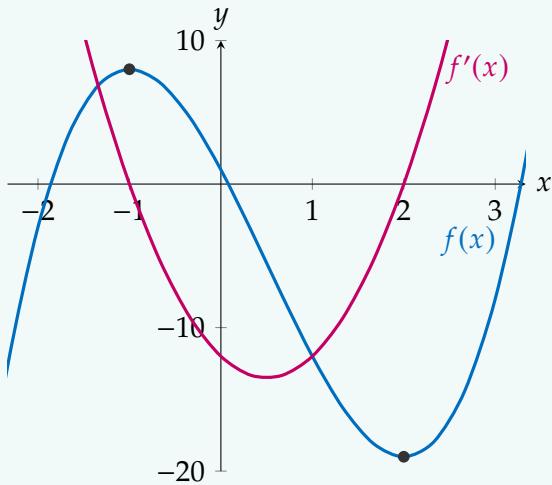
Therefore the critical points are $(2, -19)$ and $(-1, 8)$.

The first derivative test can be used to determine the intervals of increasing/decreasing and consequently we will be able to classify the critical points. Since we are only interested in the values of the derivative, it will be easier to use the factored form of the derivative, $f'(x)=6(x-2)(x+1)$

1st Derivative Test Table

| x | $x < -1$ | $x = -1$ | $-1 < x < 2$ | $x = 2$ | $x > 2$ |
|---------|----------|----------|--------------|---------|---------|
| $f'(x)$ | + | 0 | - | 0 | + |
| $f(x)$ | ↗ | → | ↘ | → | ↗ |
| C.P. | | Max | | Min | |

From the first derivative table we can classify the critical point $(2, -19)$ as a local maximum and $(-1, 8)$ as a local minimum.



18. Curve Sketching

18.0.1 Finding the vertex of a quadratic function using differentiation.

We can find the vertex of a quadratic function, $f(x)$ using differentiation by:

1. Differentiate the function: Find $f'(x)$.
2. Set the derivative equal to zero: $f'(x) = 0$.
3. Find the abscissa of the vertex by solving the equation $f'(x) = 0$ for x to find the critical x value: $x = k$.
4. Find the ordinate of the vertex by substituting the value of critical value $x = k$ into the function $f(x)$: Evaluate $f(k)$

Example 18.1 – id:20151008-110208.

Find the vertex of the quadratic function, $f(x) = ax^2 + bx + c$, using differentiation.

(S)

Solution:

1. Find the derivative of $f(x)$

$$[f(x)]' = [ax^2 + bx + c]' \quad \text{SPE(4.15)}$$

$$f'(x) = [ax^2]' + [bx]' + [c]' \quad \text{DS(7.7)}$$

$$f'(x) = a[x^2]' + b[x]' + [c]' \quad \text{DCM(7.3)}$$

$$f'(x) = 2 \cdot a \cdot x + b \cdot 1 + [c]' \quad \text{DPo(7.5)}$$

$$f'(x) = 2 \cdot a \cdot x + 1 \cdot b + [c]' \quad \text{CPM(4.6)}$$

$$f'(x) = 2ax + 1b + [c]' \quad \text{CTJ(3.6)}$$

$$f'(x) = 2ax + b + [c]' \quad \text{MId(4.9b)}$$

$$f'(x) = 2ax + b + 0 \quad \text{DC(7.1)}$$

$$f'(x) = 2ax + b \quad \text{AId(4.4b)}$$

2. Set the derivative equal to zero and solve for x .

$$f'(x) = 0$$

$$2ax + b = 0$$

$$x = -\frac{b}{2a} \text{ goto 11.9}$$

The abscissa of the vertex is $x = -\frac{b}{2a}$.

3. Find the ordinate of the vertex by substituting the argument $x = -\frac{b}{2a}$ into $f(x)$

Example 18.2 – id:20150923-152515.

Find the vertex of the parabola $y = x^2 - 2x - 6$ using differentiation.

(S)

1. Differentiate the function.

$$f(x) = x^2 - 2x - 6$$

$$f(x) = x^2 + -2x + -6 \quad \text{DOS(4.12a)}$$

$$[f(x)]' = [x^2 + -2x + -6]' \quad \text{SPE(4.15)}$$

$$f'(x) = [x^2]' + [-2x]' + [-6]' \quad \text{DS(7.7)}$$

$$f'(x) = [x^2]' + -2[x]' + [-6]' \quad \text{DCM(7.3)}$$

$$f'(x) = 2x + -2 + [-6]' \quad \text{DPo(7.5)}$$

$$f'(x) = 2x + -2 + 0 \quad \text{DC(7.1)}$$

$$f'(x) = 2x + -2 \quad \text{AId(4.4b)}$$

$$f'(x) = 2x - 2 \quad \text{DOS(4.12b)}$$

- 2 and 3. Set the derivative equal to zero and solve for x

$$2x - 2 = 0$$

$$x = 1$$

4. Find the value of $f(1)$

$$f(x) = x^2 - 2x - 6$$

$$f(1) = [1]^2 - 2[1] - 6 \quad \text{SPE(4.15)}$$

$$f(1) = -7 \quad \text{Evaluate}$$

The vertex of this parabola is the point $(1, -7)$

19. Second Derivative Test

20. Curve Sketching

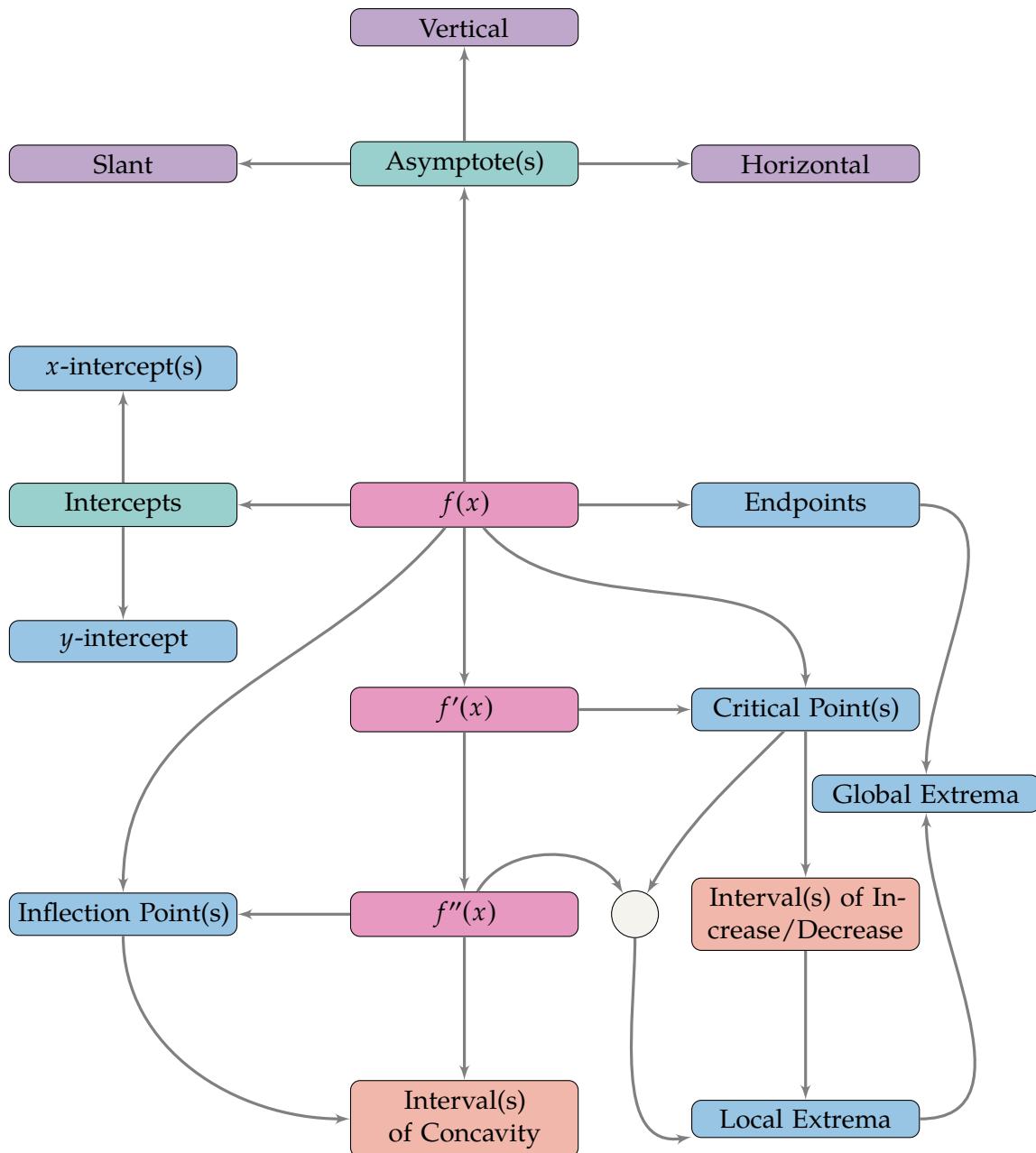


Figure 20.1: Overview of Curve Sketching

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Articles

Index

A

| | |
|-------------------------------|----|
| Additive Identity | 15 |
| Additive Inverse | 16 |
| Algebraic Limit Theorem | 25 |
| AlgebraicLimitTheorem | |
| Limit of a Constant | 25 |
| Limit of a Difference | 25 |
| Limit of a Product | 25 |
| Limit of a Quotient | 25 |
| Limit of a Sum | 25 |

C

| | |
|--------------------------|----|
| Coefficient..... | 33 |
| Common Denominator | 9 |
| Cosine Inverse | 82 |

D

| | |
|---|----|
| Definition of Subtraction..... | 17 |
| Degree of the Indeterminate | 33 |
| Degree of the Univariate Polynomial | 58 |
| Derivative | 85 |
| DerivativeRules | |
| Derivative of a Composite Function | 28 |
| Derivative of a Constant | 27 |
| Derivative of a Constant Multiple | 27 |
| Derivative of a Difference | 27 |
| Derivative of a Logarithm | 29 |
| Derivative of a Natural Exponential | 30 |
| Derivative of a Natural Logarithm | 29 |
| Derivative of a Power | 27 |
| Derivative of a Product | 28 |
| Derivative of a Quotient | 28 |
| Derivative of a Sum | 27 |
| Derivative of Cosecant | 29 |
| Derivative of Cosine | 28 |
| Derivative of Cotangent | 29 |

| | |
|---|----|
| Derivative of Secant | 29 |
| Derivative of Sine | 28 |
| Derivative of Tangent | 28 |
| Derivative Structural Rules | 27 |
| Logarithm Derivative Structural Rules | |
| 29 | |
| Monomial Derivative Rules | 27 |
| Trigonometric Derivative Structural Rules | |
| 28 | |

Derivatives

| | |
|------------------------------------|----|
| Derivative of an Exponential | 29 |
| Dyadic Operations | 9 |

E

| | |
|-----------------------|----|
| Example | |
| 20141027-075159 | 36 |
| 20141105-161225 | 56 |
| 20141106-150622 | 38 |
| 20141106-151138 | 42 |
| 20141106-152020 | 39 |
| 20141106-152339 | 51 |
| 20141106-154547 | 42 |
| 20141107-121834 | 51 |
| 20141107-131748 | 71 |
| 20141108-173613 | 41 |
| 20141108-191616 | 44 |
| 20141108-194156 | 40 |
| 20141108-194431 | 40 |
| 20141108-194709 | 43 |
| 20141109-090809 | 45 |
| 20141109-091015 | 45 |
| 20141109-092448 | 46 |
| 20141109-092651 | 46 |
| 20141109-092910 | 47 |
| 20141109-093220 | 47 |
| 20141109-093419 | 48 |
| 20141109-094928 | 48 |
| 20141109-095151 | 49 |
| 20141109-095536 | 49 |
| 20141109-095842 | 50 |

| | |
|--|--------|
| 20141109-133008 | 53 |
| 20141109-133316 | 54 |
| 20141109-140659 | 54 |
| 20141109-141019 | 55 |
| 20141109-141347 | 56 |
| 20141111-215726 | 68 |
| 20141111-222931 | 65 |
| 20141120-202042 | 35 |
| 20141120-202842 | 42 |
| 20141120-203846 | 35 |
| 20141121-093439 | 35 |
| 20141121-093747 | 34 |
| 20141121-184652 | 38 |
| 20141121-185558 | 36 |
| 20141121-190857 | 37 |
| 20141121-193636 | 37 |
| 20141124-141850 | 87 |
| 20141124-152503 | 88 |
| 20141124-153017 | 87 |
| 20141124-203850 | 91 |
| 20141124-205219 | 94 |
| 20141128-151834 | 89 |
| 20141128-155506 | 93 |
| 20141128-160248 | 92 |
| 20141206-101107 | 66 |
| 20141206-101632 | 66 |
| 20141206-102142 | 65 |
| 20141206-102404 | 67 |
| 20141206-102723 | 68 |
| 20141206-104404 | 67 |
| 20141209-142321 | 90 |
| 20141209-144203 | 90 |
| 20141209-145211 | 52 |
| 20141209-151354 | 91 |
| 20141219-212546 | 85 |
| 20150910-115935 | 91 |
| 20150923-152515 | 104 |
| 20151008-110208 | 103 |
| 20151011-154209 | 98 |
| 20151011-195002 | 89 |
| 20151012-190708 | 101 |
| 20151012-192313 | 71 |
| 20151012-201647 | 81 |
| 20151012-203549 | 81 |
| 20151015-104754 | 69 |
| 20151015-153507 | 95 |
| 20151015-155838 | 88 |
| 20151015-165037 | 94 |
| 20151015-171630 | 98 |
| 20151015-184212 | 63 |
| 20151016-063338 | 63 |
| 20151018-161315 | 59 |
| 20151018-161544 | 60 |
| 20151018-164351 | 60 |
| 20151018-164638 | 62 |
| 20151018-165132 | 59 |
| 20151018-182202 | 61 |
| 20151018-183900 | 61 |
| 20151018-184931 | 41 |
| Exponential Inverse | 82 |
| F | |
| Fraction Operation of Addition | 10 |
| Function Value Argument Substitution | 81 |
| Functions | |
| Inverses | 82 |
| G | |
| Greatest Common Divisor | 7 |
| I | |
| Identities | |
| Power Identities | 19, 20 |
| Improper Fraction | 7 |
| Indeterminate | 33 |
| L | |
| Like Terms | 34 |
| Logarithmic Inverse | 82 |
| LogarithmIdentity | |
| Logarithm Power of a Power | 20 |
| Logarithm Product of Common Base Powers | 20 |
| Logarithm Quotient of Common Base Powers | 20 |
| Logartihms | |
| Logarithm Exponent Visible | 12 |
| Logarithm to Power | 12 |
| M | |
| Multiplicative Identity | 16 |

Multiplicative Inverse 16

N

Notation

Center-Dot to Juxtaposition 12
Derivative Notation 12
Euler's first derivative 13
Euler's nth derivative 14
Euler's second derivative 13
Juxtaposition to Center-Dot 12
LaGrange's Evaluate derivative 13
LaGrange's first derivative 13
LaGrange's nth derivative 13
LaGrange's second derivative 13
Leibniz's Evaluate derivative 13
Leibniz's first derivative 13
Leibniz's nth derivative 13
Leibniz's second derivative 13
Logarithm Notation 12
Multiplication Center-Dot 11
Multiplication Juxtaposition 11
Multiplication Notation 11
Multiplication Times 11
Negation Notation 11
Power Notation 12

Number System

Integers 7
Natural Numbers 7
Rational Numbers 7
Number Systems 7

O

Operation

Operation of Addition 9
Operation of Exponentiation 9
Operation of Multiplication 9
Operation of Negation 11

P

Positive Integers 7
Power Identity 17
Power Inverse 82
Powers
Factor to Power 12

Power Negative Exponent 12
Power of a Power 19
Power of a Product of Powers 19
Power of a Quotient of Powers 19
Power to Factor 12
Power To Logarithm 12
Product Common Base Powers 19
Quotient Common Base Powers 19
Radical to Power 12
Prime Numbers 7
Proper Fraction 7
Properties
Summary of Field Properties 15
Properties of Addition 15
Property
Associative Property of Addition 15
Associative Property of Multiplication 16
Commutative Property of Addition 15
Commutative Property of Multiplication 16
Distributive Property Factoring 15, 16
Inverses 82
Properties of Equality 17
Properties of Inequality 18
Properties of Multiplication 16
Properties of Powers 17
Properties of Subtraction 17
Zero Product 17

R

Reflexive Property of Equality 17
Relatively Prime 8

S

Simplify
Degree 2 Multivariate Monomials 59
Simplifying Degree 0 Univariate Monomials 33
Sine Inverse 82
Solving Quadratic Equations
Completing the Square 72
Multiplicative Inverse 71
Power Inverse 65
Substitution Property of Equality 17
Substitution Property of Inequality 18

Symmetric Property of Equality 17

T

Tangent Inverse 82

Transitive Property of Equality 17

Transitive Property of Inequality 18

Trigonometric Identity

 Cosine Difference of Angles Identity 21

 Cosine Double Angle Identity 21

 Cosine Sum of Angles Identity 21

 Sine Difference of Angles Identity . 21

 Sine Double Angle Identity 21

 Sine Sum of Angles Identity 21

 Tangent Difference of Angles Identity
 22

 Tangent Double Angle Identity 21

 Tangent Sum of Angles Identity ... 21

 Trigonometric Cotangent Identity . 21

 Trigonometric Pythagorean Identities
 20

 Trigonometric Reciprocal Identities 20

 Trigonometric Tangent Identity 20

U

Univariate Monomial 33

Univariate Polynomial Expression 57

Z

Zero Factor Property 18

Zero Polynomial 59