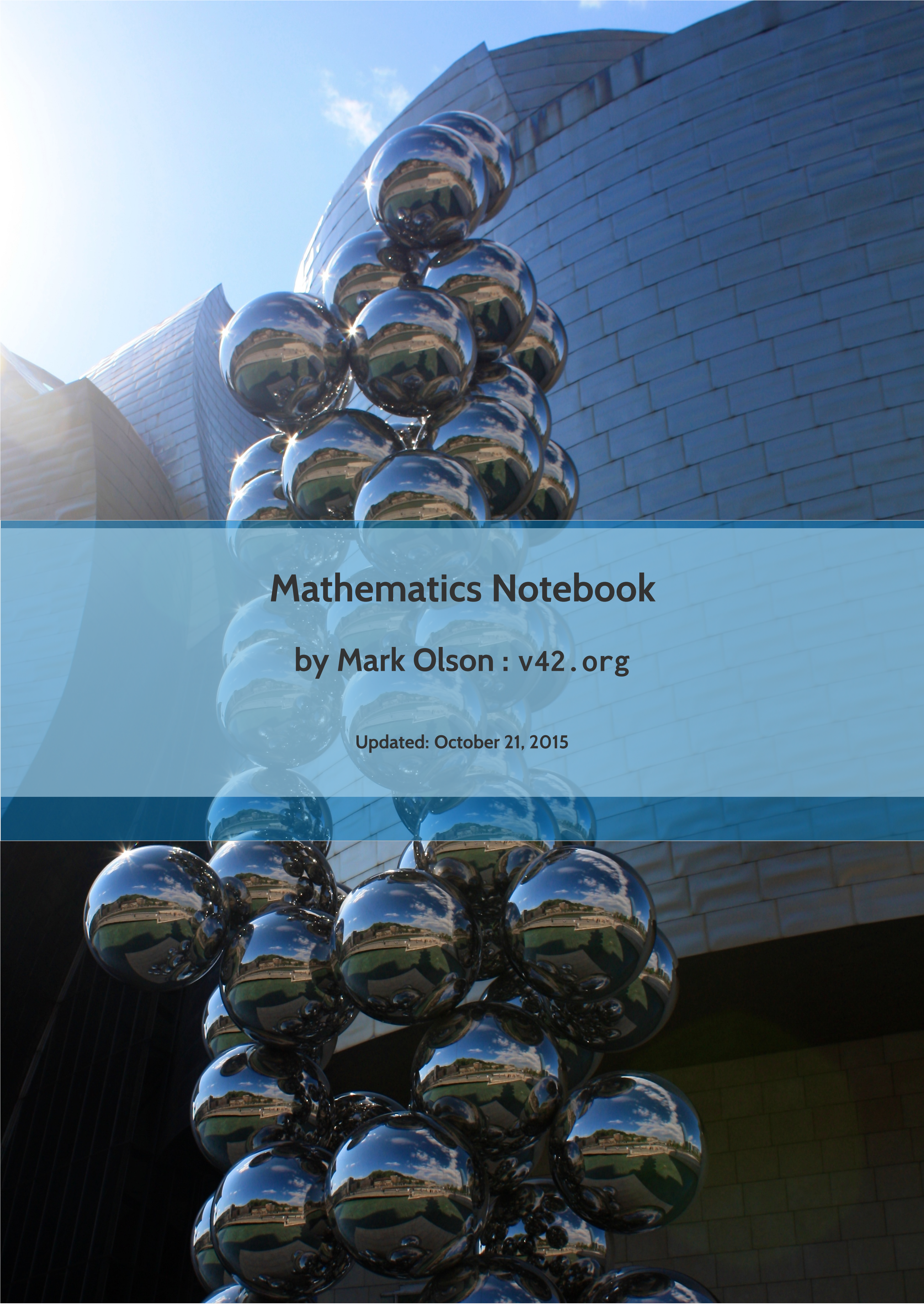

Mathematics Notebook

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Contents

Reference

1. Numbers

1.1 Number Systems

Definition 1.1.1 – Natural Numbers.

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

R 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.

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

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

Definition 1.1.2 – Integers.

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

Definition 1.1.3 – Positive Integers.

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

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 Faction. 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).

$$\underbrace{\underbrace{a}_{\text{Augend}} + \underbrace{b}_{\text{Addend}}}_{\text{Sum}} \tag{2.1}$$

More generally,

$$\underbrace{\underbrace{a}_{\text{Summand}} + \underbrace{b}_{\text{Summand}}}_{\text{Sum}} \tag{2.2}$$

Definition 2.1.2 – Operation of Subtraction (OOS).

$$\underbrace{\underbrace{a}_{\text{Minuend}} - \underbrace{b}_{\text{Subtrahend}}}_{\text{Difference}} \tag{2.3}$$

Definition 2.1.3 – Operation of Multiplication (OOM).

$$\underbrace{\underbrace{a}_{\text{Multiplicand}} \times \underbrace{b}_{\text{Multiplier}}}_{\text{Product}} \tag{2.4}$$

More generally,

$$\underbrace{\underbrace{a}_{\text{Factor}} \times \underbrace{b}_{\text{Factor}}}_{\text{Product}} \tag{2.5}$$

Definition 2.1.4 – Operation of Exponentiation (OOE).

$$\underbrace{\underbrace{b}_{base}^{\overbrace{m}^{Exponent}}}_{Power} \tag{2.6}$$

Definition 2.1.5 – Common Denominator (CD).

$$\frac{a}{b} + \frac{c}{b} = \frac{a+c}{b} \tag{2.7a}$$

$$\frac{a+c}{b} = \frac{a}{b} + \frac{c}{b} \tag{2.7b}$$

Rule 2.1.1 – Fraction Operation of Addition (FOOA).

$$\frac{a}{b} + \frac{c}{d} = \frac{ad+bc}{bd} \tag{2.8a}$$

$$\frac{ad+bc}{bd} = \frac{a}{b} + \frac{c}{d} \tag{2.8b}$$

3. Notation

3.1 Negation Notation

Notation 3.1.1 – Operation of Negation (ONeg).

$$-a = \neg a \tag{3.1a}$$
$$\neg a = -a \tag{3.1b}$$

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: $4 - -5$
- 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).

$$a \cdot b \tag{3.2}$$

Notation 3.2.2 – Multiplication Juxtaposition (MJ).

$$ab, a(b), (a)b, (a)(b), a[b], [a]b, [a][b] \tag{3.3}$$

Notation 3.2.3 – Multiplication Times (MT).

$$a \times b \tag{3.4}$$

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

$$ab = a \cdot b \tag{3.5}$$

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

$$a \cdot b = ab \tag{3.6}$$

3.3 Power Notation

Notation 3.3.1 – Power Exponent Negative Exponent (PoNegE).

$$b^{-k} = \frac{1}{b^k} \tag{3.7}$$

$$\frac{1}{b^k} = b^{-k} \tag{3.8}$$

Notation 3.3.2 – Power To Factor (PoTF).

$$a^{n} = a_1 \cdot a_2 \cdot \ldots \cdot a_{n-1} \cdot a_{n} \tag{3.9}$$

Notation 3.3.3 – Power To Logarithm (PoTL).

$$y = b^x \Rightarrow x = \log_b y \tag{3.10}$$

Notation 3.3.4 – Factor To Power (FTPo).

$$a_1 \cdot a_2 \cdot \ldots \cdot a_{n-1} \cdot a_{n} = a^{n} \tag{3.11}$$

Notation 3.3.5 – Radical To Power (RTPo).

$$\sqrt[m]{b^n} = b^{\frac{n}{m}} \tag{3.12}$$

3.4 Logarithm Notation

Notation 3.4.1 – Logarithm Exponent Visible (LEV).

$$\log_b y \Rightarrow \log_b y = x \tag{3.13}$$

Notation 3.4.2 – Logarithm to Power (LTPo).

$$x = \log_b y \Rightarrow y = b^x \tag{3.14}$$

3.5 Derivative Notation

Notation 3.5.1 – Leibniz's first derivative.

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{d\left[f(x)\right]}{\mathrm{d}x} = \frac{d}{\mathrm{d}x}\left[f(x)\right] \tag{3.15}$$

Notation 3.5.2 – Leibniz's second derivative.

$$\frac{\mathrm{d}^2y}{\mathrm{d}x^2} \tag{3.16}$$

Notation 3.5.3 – Leibniz's nth derivative.

$$\frac{\mathrm{d}^n y}{\mathrm{d}x^n} \tag{3.17}$$

Notation 3.5.4 – Leibniz's Evaluate derivative.

$$\left.\frac{\mathrm{d}y}{\mathrm{d}x}\right|_{x=a} = \frac{\mathrm{d}y}{\mathrm{d}x}(a) \tag{3.18}$$

Notation 3.5.5 – LaGrange's first derivative.

$$f'(x) \tag{3.19}$$

Notation 3.5.6 – LaGrange's second derivative.

$$f''(x) \tag{3.20}$$

Notation 3.5.7 – LaGrange's nth derivative.

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

Notation 3.5.8 – LaGrange's Evaluate derivative.

$$f'(a) \tag{3.22}$$

Notation 3.5.9 – Euler's first derivative.

$$Df = D_x f \tag{3.23}$$

Notation 3.5.10 – Euler's second derivative.

$$D^2 f = D_x^2 f \tag{3.24}$$

Notation 3.5.11 – Euler's nth derivative.

$$D^n f = D_x^n \tag{3.25}$$

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	$a+0=a=0+a$	$a\cdot 1=a=1\cdot a$
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).

$$ab=ba \tag{4.1}$$

Property 4.2.2 – Associative Property of Addition (APA).

$$a+b+c=(a+b)+c \tag{4.2a}$$
$$a+b+c=a+(b+c) \tag{4.2b}$$

Property 4.2.3 – Distributive Property Factoring (DPF).

$$ba+ca=(b+c)a \tag{4.3a}$$
$$ab+ac=a(b+c) \tag{4.3b}$$

Property 4.2.4 – Additive Identity (AId).

$$a=a+0 \tag{4.4a}$$
$$a+0=a \tag{4.4b}$$

Property 4.2.5 – Additive Inverse (AI).

$$a + (-a) = 0 \tag{4.5a}$$

4.3 Properties of Multiplication

Property 4.3.1 – Commutative Property of Multiplication (CPM).

$$a \cdot b = b \cdot a \tag{4.6}$$

Property 4.3.2 – Associative Property of Multiplication (APM).

$$a \cdot b \cdot c = (a \cdot b) \cdot c \tag{4.7a}$$

$$a \cdot b \cdot c = a \cdot (b \cdot c) \tag{4.7b}$$

Property 4.3.3 – Distributive Property Expanding (DPE).

$$a(b + c) = ab + ac \tag{4.8a}$$

$$(b + c)a = ba + ca \tag{4.8b}$$

Property 4.3.4 – Multiplicative Identity (MId).

$$a = 1a \tag{4.9a}$$

$$1a = a \tag{4.9b}$$

R If the coefficient of a univariate monomial is the multiplicative identity 4.9a, 1, then it is not shown in it's 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).

$$a \cdot \frac{1}{a} = 1 \tag{4.10a}$$

$$a \cdot a^{-1} = 1 \tag{4.10b}$$

Property 4.3.6 – Zero Product (ZPr).

$$\text{if} a \cdot b = 0, \text{ then} a = 0 \,\text{or} b = 0 \tag{4.11a}$$

4.4 Properties of Subtraction

Definition 4.4.1 – Definition of Subtraction (DOS).

$$a - b = a + \neg b \tag{4.12a}$$

$$a + \neg b = a - b \tag{4.12b}$$

4.5 Properties of Powers

Property 4.5.1 – Power Inverse (PoId).

$$1 = b^0 \tag{4.13a}$$

$$b^0 = 1 \tag{4.13b}$$

4.6 Properties of Equality

Property 4.6.1 – Reflexive Property of Equality (RPE).

$$a = a \tag{4.14a}$$

Property 4.6.2 – Substitution Property of Equality (SPE).

Given $a = b$, then

$$E(a) = E(b) \tag{4.15}$$

$E(x)$ represents any expression.

Property 4.6.3 – Symmetric Property of Equality (SyPE).

$$a = b \quad \text{then} \quad b = a \tag{4.16a}$$

Property 4.6.4 – Transitive Property of Equality (TPE).

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

Property 4.6.5 – Zero Factor Property (ZFP).

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

4.7 Properties of Inequality

Property 4.7.1 – Substitution Property of Inequality (SPIn).

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

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

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

Property 4.7.2 – Transitive Property of Inequality (TPIn).

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

5. Identities

5.1 Power Identities

Identity 5.1.1 – Power of Power (PoPo).

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

Identity 5.1.2 – Power of a Product (PoPr).

$$(a \cdot b)^k = a^k \cdot b^k \tag{5.2a}$$
$$a^k \cdot b^k = (a \cdot b)^k \tag{5.2b}$$

Identity 5.1.3 – Product Common Base Powers (PrCBPo).

$$b^m \cdot b^n = b^{m+n} \tag{5.3a}$$
$$b^{m+n} = b^m \cdot b^n \tag{5.3b}$$

Identity 5.1.4 – Quotient Common Base Powers (QCBPo).

$$\frac{b^m}{b^n} = b^{m-n} \tag{5.4a}$$
$$b^{m-n} = \frac{b^m}{b^n} \tag{5.4b}$$

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

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

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

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

5.2 Logarithm Identities

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

$$\log_b x^n = n \log_b x \tag{5.7a}$$
$$n \log_b x = \log_b x^n \tag{5.7b}$$

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

$$\log_b(mn) = \log_b m + \log_b n \tag{5.8a}$$
$$\log_b m + \log_b n = \log_b(mn) \tag{5.8b}$$

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

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

5.3 Trigonometric Identities

Identity 5.3.1 – Trigonometric Reciprocal Identities (TRId).

$$\sin\theta = \frac{1}{\csc\theta} \tag{5.10a}$$
$$\cos\theta = \frac{1}{\sec\theta} \tag{5.10b}$$
$$\cot\theta = \frac{1}{\tan\theta} \tag{5.10c}$$
$$\csc\theta = \frac{1}{\sin\theta} \tag{5.10d}$$
$$\sec\theta = \frac{1}{\cos\theta} \tag{5.10e}$$
$$\tan\theta = \frac{1}{\cot\theta} \tag{5.10f}$$

Identity 5.3.2 – Trigonometric Pythagorean Identities (TPythagId).

$$\sin^2\theta + \cos^2\theta = 1 \tag{5.11a}$$
$$\sec^2\theta = \tan^2\theta + 1 \tag{5.11b}$$
$$\csc^2\theta = 1 + \cot^2\theta \tag{5.11c}$$

Identity 5.3.3 – Trigonometric Tangent Identity (TanId).

$$\tan\theta = \frac{\sin\theta}{\cos\theta} \tag{5.12a}$$

Identity 5.3.4 – Trigonometric Cotangent Identity (CotId).

$$\cot\theta = \frac{\cos\theta}{\sin\theta} \tag{5.13a}$$

Identity 5.3.5 – Sine Double Angle Identity (SinDAId).

$$\sin 2\theta = 2\sin\theta\cos\theta \tag{5.14a}$$

Identity 5.3.6 – Cosine Double Angle Identity (CosDAId).

$$\cos 2\theta = \cos^2\theta - \sin^2\theta \tag{5.15a}$$
$$= 1 - 2\sin^2\theta \tag{5.15b}$$
$$= 2\cos^2\theta - 1 \tag{5.15c}$$

Identity 5.3.7 – Tangent Double Angle Identity (TanDAId).

$$\tan 2\theta = \frac{2\tan\theta}{1-\tan^2\theta} \tag{5.16a}$$

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

$$\sin(\theta+\phi) = \sin\theta\cos\phi + \cos\theta\sin\phi \tag{5.17a}$$

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

$$\sin(\theta-\phi) = \sin\theta\cos\phi - \cos\theta\sin\phi \tag{5.18a}$$

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

$$\cos(\theta+\phi) = \cos\theta\cos\phi - \sin\theta\sin\phi \tag{5.19a}$$

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

$$\cos(\theta-\phi) = \cos\theta\cos\phi + \sin\theta\sin\phi \tag{5.20a}$$

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

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

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

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

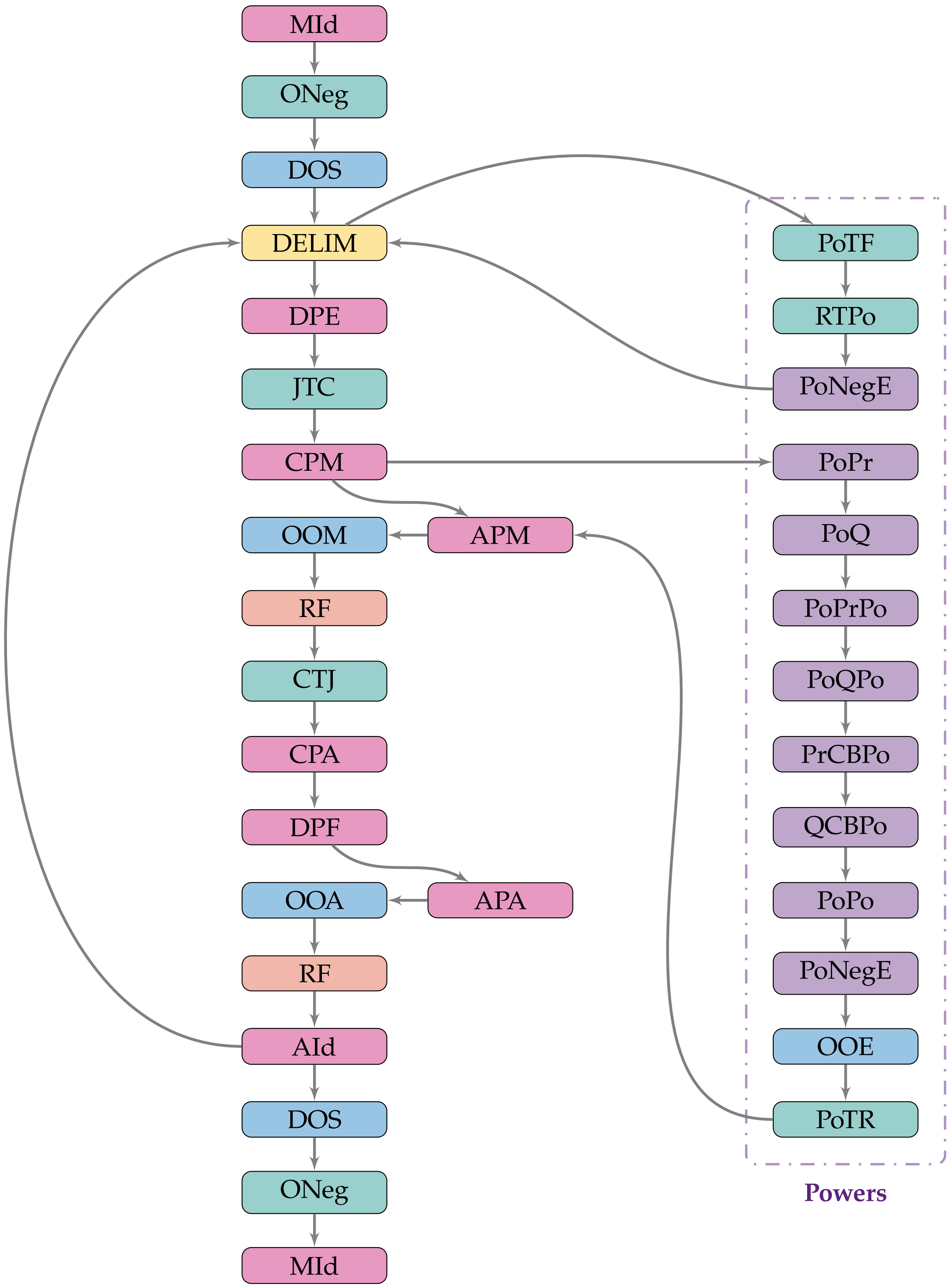


Figure 5.1: Simplifying Expressions Workflow:
Properties, Operation, Notation, Powers, Delimiters, Process, Not Used

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

$$\lim_{x \to c} [A] = A \tag{6.1}$$

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

$$\lim_{x \to c} \left[g(x) + h(x)\right] = \lim_{x \to c} g(x) + \lim_{x \to c} h(x) \tag{6.2}$$

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

$$\lim_{x \to c} \left[g(x) - h(x)\right] = \lim_{x \to c} g(x) - \lim_{x \to c} h(x) \tag{6.3}$$

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

$$\lim_{x \to c} \left[g(x) \cdot h(x)\right] = \lim_{x \to c} g(x) \cdot \lim_{x \to c} h(x) \tag{6.4}$$

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

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

7. Calculus Rules

7.1 Monomial Derivative Rules

Rule 7.1.1 – Derivative of a Constant (DC).

$$[c]' = 0 \tag{7.1}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[c] = 0 \tag{7.2}$$

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

$$[c\,f(x)]' = c\,[f(x)]' \tag{7.3}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[c\,f(x)] = c\frac{\mathrm{d}}{\mathrm{d}x}[f(x)] \tag{7.4}$$

Rule 7.1.3 – Derivative of a Power (DPo).

$$[x^n]' = nx^{n-1} \tag{7.5}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[x^n] = nx^{n-1} \tag{7.6}$$

7.2 Derivative Structural Rules

Rule 7.2.1 – Derivative of a Sum (DS).

$$[f(x) + g(x)]' = f'(x) + g'(x) \tag{7.7}$$

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

Rule 7.2.2 – Derivative of a Difference (DD).

$$[f(x) - g(x)]' = f'(x) - g'(x) \tag{7.9}$$

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

Rule 7.2.3 – Derivative of a Product (DPr).

$$[f(x)g(x)]' = f'(x)g(x) + f(x)g'(x) \tag{7.11}$$

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

Rule 7.2.4 – Derivative of a Quotient (DQ).

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

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

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

$$[f(g(x))]' = [g(x)]'\,[f(g(x))]' \tag{7.15}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[f(g(x))] = \frac{\mathrm{d}}{\mathrm{d}x}[g(x)]\,\frac{\mathrm{d}}{\mathrm{d}x}[f(g(x))] \tag{7.16}$$

7.3 Trigonometric Derivative Rules

Rule 7.3.1 – Derivative of Sine (DSin).

$$[\sin(x)]' = \cos(x) \tag{7.17}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\sin(x)] = \cos(x) \tag{7.18}$$

Rule 7.3.2 – Derivative of Cosine (DCos).

$$[\cos(x)]' = -\sin(x) \tag{7.19}$$

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

Rule 7.3.3 – Derivative of Tangent (DTan).

$$[\tan x]' = \sec^2 \tag{7.21}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\tan x] = \sec^2 \tag{7.22}$$

Rule 7.3.4 – Derivative of Cosecant (DCsc).

$$[\csc x]' = -\csc x \cot x \tag{7.23}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\csc x] = -\csc x \cot x \tag{7.24}$$

Rule 7.3.5 – Derivative of Secant (DSec).

$$[\sec x]' = \sec x \tan x \tag{7.25}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\sec x] = \sec x \tan x \tag{7.26}$$

Rule 7.3.6 – Derivative of Cotangent (DCot).

$$[\cot x]' = -\csc^2 x \tag{7.27}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\cot x] = -\csc^2 x \tag{7.28}$$

7.4 Logarithm Derivative Rules

Rule 7.4.1 – Derivative of a Logarithm (DL).

$$[\log_a x]' = \frac{1}{x \ln a} \tag{7.29}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\log_a x] = \frac{1}{x \ln a} \tag{7.30}$$

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

$$[\ln x]' = \frac{1}{x} \tag{7.31}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[\ln x] = \frac{1}{x} \tag{7.32}$$

7.5 Exponential Derivative Rules

Rule 7.5.1 – Derivative of an Exponential(DExp).

$$[a^x]' = a^x \ln a \tag{7.33}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[a^x] = a^x \ln a \tag{7.34}$$

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

$$[e^x]' = e^x \tag{7.35}$$

$$\frac{\mathrm{d}}{\mathrm{d}x}[e^x] = e^x \tag{7.36}$$

II

Arithmetic

8. Reducing Fractions

8.1 Arithmetic Expressions

Definition 8.1.1 – Reduced Fraction. A fraction of the form $\frac{m}{n}$, where $n \neq 0$, is said to be in it's reduced form if the $\gcd(m, n) = 1$

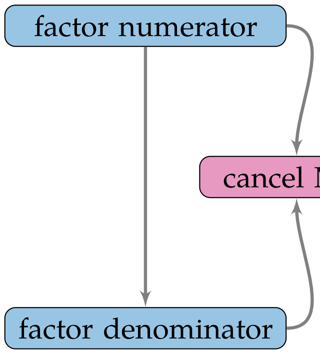


Figure 8.1: Reducing Fractions Workflow

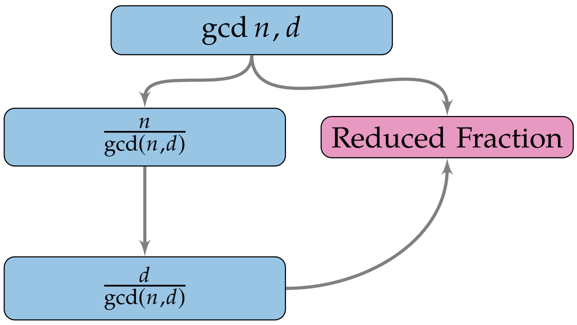


Figure 8.2: Using the $\gcd(n, d)$ to reduce the fraction $\frac{n}{d}$ Workflow

9. Arithmetic in Rational Numbers

9.1 Fractions: Operation of Addition

Example 9.1 – id:20151019-171424.

Evaluate $\frac{3}{5} - \frac{2}{4}$

S

Solution:

$$
\begin{aligned}
\frac{4}{4}\cdot\frac{3}{5}-\frac{5}{5}\cdot\frac{2}{4} &\qquad \text{MId}(4.9a)\\
\frac{12}{20}-\frac{10}{20} &\qquad \text{OOM}(2.4)\\
\frac{12-10}{20} &\qquad \text{CD}(2.7a)\\
\frac{2}{20} &\qquad \text{OOS}(2.3)\\
\frac{1}{10} &\qquad \text{RF}(8.1.1)
\end{aligned}
$$

D

Dependencies:example 10.15-20151019-170505

III

Algebra

10. 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.

10.1 Simplifying Degree 0 Univariate Monomials

Definition 10.1.1 – 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 10.1.2 – Degree of the Indeterminate.

$$x^k$$

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

Polynomial [4]

Definition 10.1.3 – Coefficient.

$$Cx^k$$

A coefficient, C is a real number multiplicative factor.

Definition 10.1.4 – 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 10.1.5 – Univariate Like Terms.

$$C_1 x^k = C_2 x^k$$

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 consequenlty giving the reader an impression that $5x^1$ and $3x^1$ are terms themselves.

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

Example 10.1 – id:20141121-093747.

Express $13x^0$ in canonical form.

S

Solution:

13 PoID(4.13b)

10.2 Simplifying Degree 1 Univariate Monomials

Example 10.2 – id:20141120-202042.

Express $5x^1$ in canonical form

S

Solution:

$5x$ MId(4.9b)

Example 10.3 – id:20141121-093439.

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

S

Solution:

$7x + 5$ 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 10.4 – 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.

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

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:

$13x$ OOA(2.1)

Example 10.5 – id:20141027-075159.

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

S

Solution:

$(7+8)\,\text{cm}$ DPF(4.3a)

$15\,\text{cm}$ 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 10.6 – 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.

$1x + 5x$ MId(4.9a)

$(1+5)x$ DPF(4.3a)

$6x$ OOA(2.1)

S

Less Steps Solution:

$1x + 5x$ MId(4.9a)

$6x$ OOA(2.1)

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

S

Less Steps Solution:

$6x$	OOA(2.1)

Example 10.7 – id:20141121-190857.

Simplify by expanding $8x - 6x$

S

Solution:

$8x + \neg 6x$	DOS(4.12a)
$(8 + \neg 6)x$	DPF(4.3a)
$2x$	OOA(2.1)

S

Less Steps Solution:

$8x + \neg 6x$	DOS(4.12a)
$2x$	OOA(2.1)

Example 10.8 – id:20141121-193636.

Simplify by expanding $3x - 5x$

S

Solution:

$3x + \neg 5x$	DOS(4.12a)
$(3 + \neg 5)x$	DPF(4.3a)
$\neg 2x$	OOA(2.1)
$-2x$	ONeg(3.1b)

S

Less Steps Solution:

$3x + \neg 5x$	DOS(4.12a)
$\neg 2x$	OOA(2.1)
$-2x$	ONeg(3.1b)

S

Less Steps Solution:

$-2x$	OOA(2.1)

Example 10.9 – id:20141106-150622.

Simplify by expanding $13x - x$

S

Solution:

$13x - 1x$	MId(4.9a)
$13x + \neg 1x$	DOS(4.12a)
$(13 + \neg 1)x$	DPF(4.3a)
$12x$	OOA(2.1)

S

Less Steps Solution:

$13x + \neg x$	DOS(4.12a)
$12x$	OOA(2.1)

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 10.10 – id:20141121-184652.

Simplify by expanding $3x + 7x + 8x$

S

$$
\begin{aligned}
(3x + 7x) + 8x &\quad \text{APA}(4.2a)\\
(3 + 7)x + 8x &\quad \text{DPF}(4.3a)\\
10x + 8x &\quad \text{OOA}(2.1)\\
(10 + 8)x &\quad \text{DPF}(4.3a)\\
18x &\quad \text{OOA}(2.1)
\end{aligned}
$$

S

Less Steps Solution:

$$
\begin{aligned}
(3x + 7x) + 8x &\quad \text{APA}(4.2a)\\
10x + 8x &\quad \text{OOA}(2.1)\\
18x &\quad \text{OOA}(2.1)
\end{aligned}
$$

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:

$$18x \quad \text{OOA}(2.1)$$

■

Example 10.11 – id:20141106-152020.

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

S

Solution:

$$
\begin{aligned}
4x - 2x - 1x &\quad \text{MId}(4.9a)\\
4x + \neg 2x + \neg 1x &\quad \text{DOS}(4.12a)\\
(4 + \neg 2)x + \neg 1x &\quad \text{DPF}(4.3a)\\
2x + \neg 1x &\quad \text{OOA}(2.1)\\
(2 + \neg 1)x &\quad \text{DPF}(4.3a)\\
1x &\quad \text{OOA}(2.1)\\
x &\quad \text{MId}(4.9b)
\end{aligned}
$$

S

Less Steps Solution:

$$\begin{aligned} 4x + \neg 2x + \neg x & \quad \text{DOS(4.12a)} \\ x & \quad \text{OOA(2.1)} \end{aligned}$$

Example 10.12 – id:20141108-194431.

Simplify by expanding $-3 \cdot 7x - 2x \cdot 4$

Solution:

$$\begin{aligned} \neg 3 \cdot 7x - 2x \cdot 4 & \quad \text{ONeg(3.1a)} \\ \neg 3 \cdot 7x + \neg 2x \cdot 4 & \quad \text{DOS(4.12a)} \\ \neg 3 \cdot 7 \cdot x + \neg 2 \cdot x \cdot 4 & \quad \text{JTC(3.5)} \\ \neg 3 \cdot 7 \cdot x + \neg 2 \cdot 4 \cdot x & \quad \text{CPM(4.6)} \\ (\neg 3 \cdot 7) \cdot x + (\neg 2 \cdot 4) \cdot x & \quad \text{APM(4.7a)} \\ \neg 21 \cdot x + \neg 8 \cdot x & \quad \text{OOM(2.4)} \\ \neg 21x + \neg 8x & \quad \text{CTJ(3.6)} \\ (\neg 21 + \neg 8)x & \quad \text{DPF(4.3a)} \\ \neg 29x & \quad \text{OOA(2.1)} \\ -29x & \quad \text{ONeg(3.1b)} \end{aligned}$$

Less Steps Solution:

$$\begin{aligned} -3 \cdot 7x + \neg 2x \cdot 4 & \quad \text{DOS(4.12a)} \\ \neg 3 \cdot 7 \cdot x + \neg 2 \cdot 4 \cdot x & \quad \text{CPM(4.6)} \\ \neg 21x + \neg 8x & \quad \text{OOM(2.4)} \\ -29x & \quad \text{OOA(2.1)} \end{aligned}$$

Example 10.13 – id:20141108-194156.

Simplify by expanding $3 \cdot 5x + 3x \cdot 4$

Solution:

$$
\begin{aligned}
3 \cdot 5 \cdot x + 3 \cdot x \cdot 4 &\qquad \text{JTC(3.5)}\\
3 \cdot 5 \cdot x + 3 \cdot 4 \cdot x &\qquad \text{CPM(4.6)}\\
(3 \cdot 5) \cdot x + (3 \cdot 4) \cdot x &\qquad \text{APM(4.7a)}\\
15 \cdot x + 12 \cdot x &\qquad \text{OOM(2.4)}\\
15x + 12x &\qquad \text{CTJ(3.6)}\\
(15 + 12)x &\qquad \text{DPF(4.3a)}\\
27x &\qquad \text{OOA(2.1)}
\end{aligned}
$$

S

Less Steps Solution:

$$
\begin{aligned}
3 \cdot 5 \cdot x + 3 \cdot 4 \cdot x &\qquad \text{CPM(4.6)}\\
15x + 12x &\qquad \text{OOM(2.4)}\\
27x &\qquad \text{OOA(2.1)}
\end{aligned}
$$

Example 10.14 – id:20141108-173613.

Simplify by expanding $8x \cdot 5$

S

Solution:

$$
\begin{aligned}
8 \cdot x \cdot 5 &\qquad \text{JTC(3.5)}\\
8 \cdot 5 \cdot x &\qquad \text{CPM(4.6)}\\
(8 \cdot 5) \cdot x &\qquad \text{APM(4.7a)}\\
40 \cdot x &\qquad \text{OOM(2.4)}\\
40x &\qquad \text{CTJ(3.6)}
\end{aligned}
$$

Example 10.15 – id:20151019-170505.

Simplify $\frac{3x}{5} - \frac{2x}{4}$

S

Solution:

$\frac{3x}{5} + \neg\frac{2x}{4}$	DOS(4.12a)
$\left(\frac{3}{5} + \neg\frac{2}{4}\right)x$	DPF(4.3a)
$\frac{1}{10}x$	OOA(2.1) goto 9.1
$\frac{1x}{10}$	OOM(2.4)
$\frac{x}{10}$	MId(4.9b)

10.3 Simplifying Degree 2 Univariate Monomials

Example 10.16 – id:20151018-184931.
Simplify $x \cdot x$

S

Solution:

$1x^1 \cdot 1x^1$	MId(4.9a)
$1x^{(1+1)}$	PrCBPo(5.3a)
$1x^2$	OOA(2.1)
x^2	MId(4.9b)

Example 10.17 – id:20141120-202842.

Express by expanding $1x^2$ in canonical form.

S

Solution:

x^2	MId(4.9b)

Example 10.18 – id:20151021-065906.
Simplify $(6\,\mathrm{m})(12\,\mathrm{m})$

S

Solution:

$6 \cdot \mathrm{m} \cdot 12 \cdot \mathrm{m}$	JTC(3.5)
$6 \cdot 12 \cdot \mathrm{m} \cdot \mathrm{m}$	CPM(4.6)
$6 \cdot 12 \cdot \mathrm{m}^2$	PrCBPo(5.3a)
$72 \cdot \mathrm{m}^2$	OOM(2.4)
$72\,\mathrm{m}^2$	CTJ(3.6)

Example 10.19 – id:20141106-151138.

Simplify by expanding $4x^2 + 12x^2$

S

Solution:

$(4 + 12)x^2$	DPF(4.3a)
$16x^2$	OOA(2.1)

S

Less Steps Solution:

$16x^2$	OOA(2.1)

Example 10.20 – id:20141106-154547.

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

S

Solution:

$1x^2 - 1x + 1x^2 + 1x$	MId(4.9a)
$1x^2 + \neg 1x + 1x^2 + 1x$	DOS(4.12a)
$1x^2 + 1x^2 + \neg 1x + 1x$	CPA(4.1)
$(1 + 1)x^2 + (\neg 1 + 1)x$	DPF(4.3a)
$2x^2 + 0x$	OOA(2.1)
$2x^2$	AId(4.4b)

S

Less Steps Solution:

$x^2 + \neg x + x^2 + x$	DOS(4.12a)
$x^2 + x^2 + \neg x + x$	CPA(4.1)
$2x^2$	OOA(2.1)

Example 10.21 – id:20141108-194709.

Simplify by expanding $-2x4x - x \cdot -x3$

S

Solution:

$-2x4x - 1x \cdot 1x3$	MId(4.9a)
$\neg 2x4x - 1x \cdot 1x3$	ONeg(3.1a)
$\neg 2 \cdot x \cdot 4 \cdot x + \neg 1 \cdot x \cdot 1 \cdot x \cdot 3$	JTC(3.5)
$\neg 2 \cdot 4 \cdot x \cdot x + \neg 1 \cdot \neg 1 \cdot 3 \cdot x \cdot x$	CPM(4.6)
$\neg 2 \cdot 4 \cdot x^2 + \neg 1 \cdot \neg 1 \cdot 3 \cdot x^2$	PrCBPo(5.3a)
$(\neg 2 \cdot 4) \cdot x^2 + (\neg 1 \cdot \neg 1 \cdot 3)x^2$	APM(4.7a)
$\neg 8x^2 + 3x^2$	OOM(2.4)
$(\neg 8 + 3)x^2$	DPF(4.3a)
$\neg 5x^2$	OOA(2.1)
$-5x^2$	ONeg(3.1b)

S

Less Steps Solution:

$-2x4x + \neg x \cdot -x3$	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(2.4)
$-5x^2$	OOA(2.1)

Example 10.22 – id:20141108-191616.

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

S

Solution:

$$\begin{aligned}
\neg 5x \cdot 4x &\qquad \text{ONeg}(3.1a)\\
\neg 5 \cdot x \cdot 4 \cdot x &\qquad \text{JTC}(3.5)\\
\neg 5 \cdot 4 \cdot x \cdot x &\qquad \text{CPM}(4.6)\\
\neg 5 \cdot 4 \cdot x^2 &\qquad \text{PrCBPo}(5.3a)\\
(\neg 5 \cdot 4) \cdot x^2 &\qquad \text{APM}(4.7a)\\
\neg 20 \cdot x^2 &\qquad \text{OOM}(2.4)\\
\neg 20x^2 &\qquad \text{CTJ}(3.6)\\
-20x^2 &\qquad \text{ONeg}(3.1b)
\end{aligned}$$

S

Less Steps Solution:

$$\begin{aligned}
\neg 5 \cdot 4 \cdot x \cdot x &\qquad \text{CPM}(4.6)\\
\neg 5 \cdot 4 \cdot x^2 &\qquad \text{PrCBPo}(5.3a)\\
-20x^2 &\qquad \text{OOM}(2.4)
\end{aligned}$$

10.4 Simplifying Degree 3 Univariate Monomials

10.5 Simplifying Degree 1 Univariate Binomials

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

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 10.23 – 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(2.4)
$5x + 25$	CTJ(3.6)

S

Less Steps Solution:

$5x + 20$	DPE(4.8a)

Example 10.24 – id:20141109-091015.

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

S

Solution:

$5(3x + \neg 9)$	DOS(4.12a)
$5 \cdot 3x + 5 \cdot \neg 9$	DPE(4.8a)
$5 \cdot 3 \cdot x + 5 \cdot \neg 9$	JTC(3.5)
$15 \cdot x + \neg 45$	OOM(2.4)
$15x + \neg 45$	CTJ(3.6)
$15x - 45$	DOS(4.12b)

S

Less Steps Solution:

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

Example 10.25 – id:20141109-092448.

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

S

Solution:

$\neg 1(5x+7)$	MId(4.9a)
$\neg 1 \cdot 5x + \neg 1 \cdot 7$	DPE(4.8a)
$\neg 1 \cdot 5 \cdot x + \neg 1 \cdot 7$	JTC(3.5)
$\neg 5 \cdot x + \neg 7$	OOM(2.4)
$\neg 5x + \neg 7$	CTJ(3.6)
$\neg 5x - 7$	DOS(4.12b)
$-5x - 7$	ONeg(3.1b)

S

Less Steps Solution:

$-5x - 7$	DPE(4.8a)

■

Example 10.26 – id:20141109-092651.

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

S

Solution:

$\neg 13(7x + \neg 9)$	DOS(4.12a)
$\neg 13 \cdot 7x + \neg 13 \cdot \neg 9$	DPE(4.8a)
$\neg 13 \cdot 7 \cdot x + \neg 13 \cdot \neg 9$	JTC(3.5)
$\neg 91 \cdot x + 117$	OOM(2.4)
$\neg 91x + 117$	CTJ(3.6)
$-91x + 117$	ONeg(3.1b)

S

Less Steps Solution:

$-13(7x + \neg 9)$	DOS(4.12a)
$-91x + 117$	DPE(4.8a)

■

Example 10.27 – id:20141109-092910.

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

S

Solution:

$a(1x+b)$	MId(4.9a)
$a \cdot 1x + a \cdot b$	DPE(4.8a)
$a \cdot 1 \cdot x + a \cdot b$	JTC(3.5)
$1 \cdot a \cdot x + a \cdot b$	CPM(4.6)
$1ax + ab$	JTC(3.5)
$ax + ab$	MId(4.9b)

S

Less Steps Solution:

$ax + ab$	DPE(4.8a)

■

Example 10.28 – id:20141109-093220.

Simplify by expanding $5(x+2)+4$

S

Solution:

$5(1x+2)+4$	MId(4.9a)
$5 \cdot 1x + 5 \cdot 2 + 4$	DPE(4.8a)
$5 \cdot 1 \cdot x + 5 \cdot 2 + 4$	JTC(3.5)
$5 \cdot x + 10 + 4$	OOM(2.4)
$5x + 10 + 4$	CTJ(3.6)
$5x + 14$	OOA(2.1)

S

Less Steps Solution:

$5x + 10 + 4$	DPE(4.8a)
$5x + 14$	OOA(2.1)

Example 10.29 – id:20141109-093419.

Simplify by expanding $7x + 5(4x + 8)$

S

Solution:

$7x + 5 \cdot 4x + 5 \cdot 8$	DPE(4.8a)
$7 \cdot x + 5 \cdot 4 \cdot x + 5 \cdot 8$	JTC(3.5)
$7 \cdot x + 20 \cdot x + 40$	OOM(2.4)
$7x + 20x + 40$	CTJ(3.6)
$(7 + 20)x + 40$	DPF(4.3a)
$27x + 40$	OOA(2.1)

Example 10.30 – id:20141109-094928.

Simplify by expanding $4(3x + 4) + x + 6$

S

Solution:

$4(3x + 4) + 1x + 6$	MId(4.9a)
$4 \cdot 3x + 4 \cdot 4 + 1x + 6$	DPE(4.8a)
$4 \cdot 3 \cdot x + 4 \cdot 4 + 1 \cdot x + 6$	JTC(3.5)
$12 \cdot x + 16 + 1 \cdot x + 6$	OOM(2.4)
$12x + 16 + 1x + 6$	CTJ(3.6)
$12 + 1x + 16 + 6$	CPA(4.1)
$(12 + 1)x + 16 + 6$	DPF(4.3a)
$13x + 22$	OOA(2.1)

S

Less Steps Solution:

$12x + 16 + x + 6$	DPE(4.8a)
$12x + x + 16 + 6$	CPA(4.1)
$13x + 22$	OOA(2.1)

Example 10.31 – id:20141109-095151.

Simplify by expanding $5(x - 4) + 3x - 5$

Solution:

$5(1x - 4) + 3x - 5$	MId(4.9a)
$5(1x + \neg 4) + 3x + \neg 5$	DOS(4.12a)
$5 \cdot 1x + 5 \cdot \neg 4 + 3x + \neg 5$	DPE(4.8a)
$5 \cdot 1 \cdot x + 5 \cdot \neg 4 + 3 \cdot x + \neg 5$	JTC(3.5)
$5 \cdot x + \neg 20 + 3 \cdot x + \neg 5$	OOM(2.4)
$5x + \neg 20 + 3x + \neg 5$	JTC(3.5)
$5x + 3x + \neg 20 + \neg 5$	CPA(4.1)
$(5 + 3)x + \neg 20 + \neg 5$	DPF(4.3a)
$8x + \neg 25$	OOA(2.1)
$8x - 25$	DOS(4.12b)

Less Steps Solution:

$5(x + \neg 4) + 3x + \neg 5$	DOS(4.12a)
$5x + \neg 20 + 3x + \neg 5$	DPE(4.8a)
$5x + 3x + \neg 20 + \neg 5$	CPA(4.1)
$8x + \neg 25$	OOA(2.1)
$8x - 25$	DOS(4.12b)

Example 10.32 – id:20141109-095536.

Simplify by expanding $8x - 5 - 4(x - 3)$

Solution:

$$
\begin{aligned}
8x - 5 - 4(1x - 3) & \qquad \text{MId}(4.9a)\\
8x + \neg 5 + \neg 4(1x + \neg 3) & \qquad \text{DOS}(4.12a)\\
8x + \neg 5 + \neg 4 \cdot 1x + \neg 4 \cdot \neg 3 & \qquad \text{DPE}(4.8a)\\
8 \cdot x + \neg 5 + \neg 4 \cdot 1 \cdot x + \neg 4 \cdot \neg 3 & \qquad \text{JTC}(3.5)\\
8 \cdot x + \neg 5 + \neg 4 \cdot x + 12 & \qquad \text{OOM}(2.4)\\
8x + \neg 5 + \neg 4x + 12 & \qquad \text{CTJ}(3.6)\\
8x + \neg 4x + \neg 5 + 12 & \qquad \text{CPA}(4.1)\\
(8 + \neg 4)x + \neg 5 + 12 & \qquad \text{DPF}(4.3a)\\
4x + 7 & \qquad \text{OOA}(2.1)
\end{aligned}
$$

S

Less Steps Solution:

$$
\begin{aligned}
8x + \neg 5 + \neg 4(x + \neg 3) & \qquad \text{DOS}(4.12a)\\
8x + \neg 5 + \neg 4x + 12 & \qquad \text{DPE}(4.8a)\\
8x + \neg 4x + \neg 5 + 12 & \qquad \text{CPA}(4.1)\\
4x + 7 & \qquad \text{OOA}(2.1)
\end{aligned}
$$

Example 10.33 – id:20141109-095842.

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

S

Solution:

$$
\begin{aligned}
5 \cdot x + 5 \cdot 3 + 3 \cdot x + 3 \cdot 2 & \qquad \text{DPE}(4.8a)\\
5 \cdot x + 15 + 3 \cdot x + 6 & \qquad \text{OOM}(2.4)\\
5x + 15 + 3x + 6 & \qquad \text{CTJ}(3.6)\\
5x + 3x + 15 + 6 & \qquad \text{CPA}(4.1)\\
(3 + 5)x + 15 + 6 & \qquad \text{DPF}(4.3a)\\
8x + 21 & \qquad \text{OOA}(2.1)
\end{aligned}
$$

S

Less Steps Solution:

$5x + 15 + 3x + 6$	DPE(4.8a)
$5x + 3x + 15 + 6$	CPA(4.1)
$8x + 21$	OOA(2.1)

Example 10.34 – id:20151019-165511.
Simplify by expanding $10x - 2(x + 5) - (x - 3)$

S

Solution:

$10x - 2(1x + 5) - 1(1x - 3)$	MId(4.9a)
$10x + \neg 2(1x + 5) + \neg 1(1x + \neg 3)$	DOS(4.12a)
$10x + \neg 2 \cdot 1x + \neg 2 \cdot 5 + \neg 1 \cdot 1x + \neg 1 \cdot \neg 3$	DPE(4.8a)
$10 \cdot x + \neg 2 \cdot 1 \cdot x + \neg 2 \cdot 5 + \neg 1 \cdot 1 \cdot x + \neg 1 \cdot \neg 3$	JTC(3.5)
$10 \cdot x + \neg 2 \cdot x + \neg 10 + \neg 1 \cdot x + 3$	OOM(2.4)
$10x + \neg 2x + \neg 10 + \neg 1x + 3$	CTJ(3.6)
$10x + \neg 2x + \neg 1x + \neg 10 + 3$	CPA(4.1)
$7x + \neg 7$	OOA(2.1)
$7x - 7$	DOS(4.12b)

10.6 Simplifying Degree 2 Univariate Binomials

Example 10.35 – id:20141106-152339.

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

S

Solution:

$3x^2 + 5x^2 + 2x + 4x$	CPA(4.1)
$(3 + 5)x^2 + (2 + 4)x$	DPF(4.3a)
$8x^2 + 6x$	OOA(2.1)

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

$(4x + 3)2x$	DPF(4.3a)

S

Less Steps Solution:

$3x^2 + 5x^2 + 2x + 4x$	CPA(4.1)
$8x^2 + 6x$	OOA(2.1)

Example 10.36 – id:20151020-214228.
Simplify $x(-2x + 25)$

S

Solution:

$1x(-2x + 25)$	MId(4.9a)
$1x(\neg 2x + 25)$	ONeg(3.1a)
$1x \cdot \neg 2x + 1x \cdot 25$	DPE(4.8a)
$1 \cdot x \cdot \neg 2 \cdot x + 1 \cdot x \cdot 25$	JTC(3.5)
$1 \cdot \neg 2 \cdot x \cdot x + 1 \cdot 25 \cdot x$	CPM(4.6)
$1 \cdot \neg 2 \cdot x^2 + 1 \cdot 25 \cdot x$	PrCBPo(5.3a)
$\neg 2 \cdot x^2 + 25 \cdot x$	OOM(2.4)
$\neg 2x^2 + 25x$	CTJ(3.6)
$-2x^2 + 25x$	ONeg(3.1b)

D

Dependencies:example 23.1-20151020-171605

Example 10.37 – id:20141107-121834.

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

S

Solution:

$\left(\sqrt{9-1x^2}\right)^2$	MId(4.9a)
$\left(\sqrt{9+\neg 1x^2}\right)^2$	DOS(4.12a)
$\left[\left(9+\neg x^2\right)^{\frac{1}{2}}\right]^2$	RTPo(3.12)
$9+\neg 1x^2$	PoPo(5.1a)
$\neg 1x^2+9$	CPA(4.1)
$\neg x^2+9$	MId(4.9a)
$-x^2+9$	ONeg(3.1b)

S

Less Steps Solution:

$9-x^2$	PoPo(5.1a)

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

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

D

Dependencies:example **??**-20141105-144223

Example 10.38 – id:20141209-145211.

Simplify by expanding $2x(2x+4)+x^2\cdot 2\cdot 1+0$

S

Solution:

$$
\begin{array}{rr}
2x\cdot 2x+2x\cdot 4+x^2\cdot 2\cdot 1+0 & \text{DPE(4.8a)}\\
2\cdot x\cdot 2\cdot x+2\cdot x\cdot 4+x^2\cdot 2\cdot 1+0 & \text{JTC(3.5)}\\
2\cdot 2\cdot x\cdot x+2\cdot 4\cdot x+2\cdot 1\cdot x^2+0 & \text{CPM(4.6)}\\
2\cdot 2\cdot x^2+2\cdot 4\cdot x+2\cdot 1\cdot x^2+0 & \text{PrCBPo(5.3a)}\\
4\cdot x^2+8\cdot x+2\cdot x^2+0 & \text{OOM(2.4)}\\
4x^2+8x+2x^2+0 & \text{CTJ(3.6)}\\
4x^2+2x^2+8x+0 & \text{CPA(4.1)}\\
(4+2)x^2+8x+0 & \text{DPF(4.3a)}\\
6x^2+8x+0 & \text{OOA(2.1)}\\
6x^2+8x & \text{AId(4.4b)}
\end{array}
$$

D

Dependencies:example 17.8-20141209-144203 ▪

10.7 Simplifying Degree 2 Univariate Trinomials

Example 10.39 – id:20141109-133008.

Simplify by expanding $(x+5)(x-8)$

S

Solution:

$$
\begin{array}{rr}
(1x+5)(1x-8) & \text{MId(4.9a)}\\
(1x+5)(1x+\neg 8) & \text{DOS(4.12a)}\\
1x(1x+\neg 8)+5(1x+\neg 8) & \text{DPE(4.8b)}\\
1x\cdot 1x+1x\cdot\neg 8+5\cdot 1x+5\cdot\neg 8 & \text{DPE(4.8a)}\\
1\cdot x\cdot 1\cdot x+1\cdot x\cdot\neg 8+5\cdot 1\cdot x+5\cdot\neg 8 & \text{JTC(3.5)}\\
1\cdot 1\cdot x\cdot x+\neg 8\cdot 1\cdot x+1\cdot 5\cdot x+\neg 8\cdot 5 & \text{CPM(4.6)}\\
1\cdot 1\cdot x^2+\neg 8\cdot 1\cdot x+1\cdot 5\cdot x+\neg 8\cdot 5 & \text{PrCBPo(5.3a)}\\
1\cdot x^2+\neg 8\cdot x+5\cdot x+\neg 40 & \text{OOM(2.4)}\\
1x^2+\neg 8x+5x+\neg 40 & \text{CTJ(3.6)}\\
1x^2+\neg 3x+\neg 40 & \text{OOA(2.1)}\\
1x^2-3x-40 & \text{DOS(4.12b)}\\
x^2-3x-40 & \text{MId(4.9b)}
\end{array}
$$

S

Less Steps Solution:

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

■

Example 10.40 – id:20141109-133316.

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

S

Solution:

$$\begin{array}{rr}
(1x+a)(1x+b) & \text{MId}(4.9a) \\
1x(1x+b)+a(1x+b) & \text{DPE}(4.8b) \\
1x\cdot 1x+1x\cdot b+a\cdot 1x+a\cdot b & \text{DPE}(4.8a) \\
1\cdot x\cdot 1\cdot x+1\cdot x\cdot b+a\cdot 1\cdot x+a\cdot b & \text{JTC}(3.5) \\
1\cdot 1\cdot x\cdot x+1\cdot b\cdot x+1\cdot a\cdot x+a\cdot b & \text{CPM}(4.6) \\
1\cdot 1\cdot x^2+1\cdot b\cdot x+1\cdot a\cdot x+a\cdot b & \text{PrCBPo}(5.3a) \\
1\cdot x^2+1\cdot b\cdot x+1\cdot a\cdot x+a\cdot b & \text{OOM}(2.4) \\
1x^2+1bx+1ax+ab & \text{CTJ}(3.6) \\
1x^2+(1b+1a)x+ab & \text{DPF}(4.3a) \\
x^2+(b+a)x+ab & \text{MId}(4.9b)
\end{array}$$

S

Less Steps Solution:

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

■

Example 10.41 – id:20141109-140659.

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

S

Solution:

$$
\begin{aligned}
2x(5x+13)+3(5x+13) &\quad \text{DPE(4.8b)}\\
2x\cdot 5x+2x\cdot 13+3\cdot 5x+3\cdot 13 &\quad \text{DPE(4.8a)}\\
2\cdot x\cdot 5\cdot x+2\cdot x\cdot 13+3\cdot 5\cdot x+3\cdot 13 &\quad \text{JTC(3.5)}\\
2\cdot 5\cdot x\cdot x+2\cdot 13\cdot x+5\cdot 3\cdot x+3\cdot 13 &\quad \text{CPM(4.6)}\\
2\cdot 5\cdot x^2+2\cdot 13\cdot x+5\cdot 3\cdot x+3\cdot 13 &\quad \text{PrCBPo(5.3a)}\\
10\cdot x^2+26\cdot x+16\cdot x+39 &\quad \text{OOM(2.4)}\\
10x^2+26x+15x+39 &\quad \text{CTJ(3.6)}\\
10x^2+41x+39 &\quad \text{OOA(2.1)}
\end{aligned}
$$

S

Less Steps Solution:

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

■

Example 10.42 – id:20141109-141019.

Simplify by expanding $(-3x-5)(7x+8)$

S

Solution:

$$
\begin{aligned}
(\neg 3x-5)(7x+8) &\quad \text{ONeg(3.1a)}\\
(\neg 3x+\neg 5)(7x+8) &\quad \text{DOS(4.12a)}\\
\neg 3x(7x+8)+\neg 5(7x+8) &\quad \text{DPE(4.8b)}\\
\neg 3x\cdot 7x+\neg 3x\cdot 8+\neg 5\cdot 7x+\neg 5\cdot 8 &\quad \text{DPE(4.8a)}\\
\neg 3\cdot x\cdot 7\cdot x+\neg 3\cdot x\cdot 8+\neg 5\cdot 7\cdot x+\neg 5\cdot 8 &\quad \text{JTC(3.5)}\\
\neg 3\cdot 7\cdot x\cdot x+\neg 3\cdot 8\cdot x+\neg 5\cdot 7\cdot x+\neg 5\cdot 8 &\quad \text{CPM(4.6)}\\
\neg 3\cdot 7\cdot x^2+\neg 3\cdot 8\cdot x+\neg 5\cdot 7\cdot x+\neg 5\cdot 8 &\quad \text{PrCBPo(5.3a)}\\
\neg 21\cdot x^2+\neg 24\cdot x+\neg 35\cdot x+\neg 40 &\quad \text{OOM(2.4)}\\
\neg 21x^2+\neg 24x+\neg 35x+\neg 40 &\quad \text{CTJ(3.6)}\\
\neg 21x^2+\neg 59x+\neg 40 &\quad \text{OOA(2.1)}\\
\neg 21x^2-59x-40 &\quad \text{DOS(4.12b)}\\
-21x^2-59x-40 &\quad \text{ONeg(3.1b)}
\end{aligned}
$$

S

Less Steps Solution:

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

■

Example 10.43 – id:20141109-141347.

Simplify by expanding $(ax + b)(cx + d)$, where $a, b, c, d \in \mathbb{Z}$

S

Solution:

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

S

Less Steps Solution:

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

■

Example 10.44 – id:20141105-161225.

Simplify by expanding $\left(2 - \frac{x}{2}\right)^2$.

S

Solution:

$$\begin{aligned}
\left(2 - \frac{1x}{2}\right)^2 && \text{MId(4.9a)}\\
\left(2 + \neg\frac{1x}{2}\right)^2 && \text{DOS(4.12a)}\\
\left(2 + \neg\frac{1x}{2}\right)\left(2 + \neg\frac{1x}{2}\right) && \text{PoTF(3.9)}\\
2\left(2 + \neg\frac{1x}{2}\right) + \neg\frac{1x}{2}\left(2 + \neg\frac{1x}{2}\right) && \text{DPE(4.8b)}\\
2\cdot 2 + 2\cdot\neg\frac{1x}{2} + \neg\frac{1x}{2}\cdot 2 + \neg\frac{1x}{2}\cdot\neg\frac{1x}{2} && \text{DPE(4.8a)}\\
2\cdot 2 + 2\cdot\neg\frac{1}{2}\cdot x + \neg\frac{1}{2}\cdot x\cdot 2 + \neg\frac{1}{2}\cdot x\cdot\neg\frac{1}{2}\cdot x && \text{JTC(3.5)}\\
2\cdot 2 + 2\cdot\neg\frac{1}{2}\cdot x + \neg\frac{1}{2}\cdot 2\cdot x + \neg\frac{1}{2}\cdot\neg\frac{1}{2}\cdot x\cdot x && \text{CPM(4.6)}\\
2\cdot 2 + 2\cdot\neg\frac{1}{2}\cdot x + \neg\frac{1}{2}\cdot 2\cdot x + \neg\frac{1}{2}\cdot\neg\frac{1}{2}\cdot x^2 && \text{PrCBPo(5.3a)}\\
4 + \neg 1\cdot x + \neg 1\cdot x + \frac{1}{4}\cdot x^2 && \text{OOM(2.4)}\\
4 + \neg 1x + \neg 1x + \frac{1}{4}x^2 && \text{CTJ(3.6)}\\
\frac{1}{4}x^2 + \neg 1x + \neg 1x + 4 && \text{CPA(4.1)}\\
\frac{1}{4}x^2 + \neg 2x + 4 && \text{OOA(2.1)}\\
\frac{1}{4}x^2 - 2x + 4 && \text{DOS(4.12b)}
\end{aligned}$$

Less Steps Solution:

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

10.8 Simplifying Degree n Univariate Polynomials

Definition 10.8.1 – Univariate Polynomial Expression.

$$\sum_{k=0}^{n} C_k x^n = C_n x^n + C_{n-1}x^{n-1} + \cdots + C_k x^k + \cdots + C_2 x^2 + C_1 x^1 + \underbrace{C_0}_{C_0 x^0} \tag{10.1}$$

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 10.8.2 – Degree of the Univaritate 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.

11. Simplifying Multivariate Monomials

Definition 11.0.3 – 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]

11.1 Simplifying Degree -1 Multivariate Monomials

Example 11.1 – id:20151018-165132.
Simplify $xy - xy$

S

Solution:

$$\begin{array}{rr} 1xy - 1xy & \text{MId}(4.9a) \\ 1xy + \neg 1xy & \text{DOS}(4.12a) \\ (1 + \neg 1)xy & \text{DPF}(4.3a) \\ 0xy & \text{OOA}(2.1) \\ 0 & \text{AId}(4.4b) \end{array}$$

D

Dependencies:example 11.8-20151018-164638

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 polynomial11.0.3. The zero polynomial is the additive identity.

11.2 Simplifying Degree 2 Multivariate Monomials

Example 11.2 – id:20151018-161315.
Simplify by expanding $4x2y$

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(2.4)
$8xy$	CTJ(3.6)

■

11.3 Simplifying Degree 2 Multivariate Binomials

Example 11.3 – id:20151020-175447.
Simplify $x + y + x$

S

Solution:

$1x + 1y + 1x$	MId(4.9a)	
$1x + 1x + 1y$	CPA(4.1)$(1+1)x + 1y$	DPF(4.3a)
$2x + 1y$	OOA(2.1)	
$2x + y$	MId(4.9b)	

D

Dependencies:example 23.1-20151020-171605

■

Example 11.4 – id:20151018-164351.

Simplify $10xy + 21xy$

S

Solution:

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

D

Dependencies:example 11.5-20151018-161544

■

11.4 Simplifying Degree 2 Multivariate Trinomials

Example 11.5 – id:20151018-161544.
Simplify by expanding $(2x+3y)(7x+5y)$

S

Solution:

$$\begin{aligned}
2x(7x+5y)+3y(7x+5y) &\quad \text{DPE(4.8b)}\\
2x\cdot 7x+2x\cdot 5y+3y\cdot 7x+3y\cdot 5y &\quad \text{DPE(4.8a)}\\
2\cdot x\cdot 7\cdot x+2\cdot x\cdot 5\cdot y+3\cdot y\cdot 7\cdot x+3\cdot y\cdot 5\cdot y &\quad \text{JTC(3.5)}\\
2\cdot 7\cdot x\cdot x+2\cdot 5\cdot x\cdot y+3\cdot 7\cdot x\cdot y+3\cdot 5\cdot y\cdot y &\quad \text{CPM(4.6)}\\
2\cdot 7\cdot x^2+2\cdot 5\cdot x\cdot y+3\cdot 7\cdot x\cdot y+3\cdot 5\cdot y^2 &\quad \text{PrCBPo(5.3a)}\\
14\cdot x^2+10\cdot x\cdot y+21\cdot x\cdot y+15\cdot y^2 &\quad \text{OOM(2.4)}\\
14x^2+10xy+21xy+15y^2 &\quad \text{CTJ(3.6)}\\
14x^2+31xy+15y^2 &\quad \text{OOA(2.1) goto 11.4}
\end{aligned}$$

■

Example 11.6 – id:20151018-183900.
Simplify by expanding $(x+y)^2$

S

Solution:

$$\begin{aligned}
(1x+1y)^2 &\quad \text{MId(4.9a)}\\
(1x+1y)(1x+1y) &\quad \text{PoTF(3.9)}\\
1x(1x+1y)+1y(1x+1y) &\quad \text{DPE(4.8b)}\\
1x\cdot 1x+1x\cdot 1y+1y\cdot 1x+1y\cdot 1y &\quad \text{DPE(4.8a)}\\
1\cdot x\cdot 1\cdot x+1\cdot x\cdot 1\cdot y+1\cdot y\cdot 1\cdot x+1\cdot y\cdot 1\cdot y &\quad \text{JTC(3.5)}\\
1\cdot 1\cdot x\cdot x+1\cdot 1\cdot x\cdot y+1\cdot 1\cdot x\cdot y+1\cdot 1\cdot y\cdot y &\quad \text{CPM(4.6)}\\
1\cdot 1\cdot x^2+1\cdot 1\cdot x\cdot y+1\cdot 1\cdot x\cdot y+1\cdot 1\cdot y^2 &\quad \text{PrCBPo(5.3a)}\\
1\cdot x^2+1\cdot x\cdot y+1\cdot x\cdot y+1\cdot y^2 &\quad \text{OOM(2.4)}\\
1x^2+1xy+1xy+1y^2 &\quad \text{CTJ(3.6)}\\
1x^2+(1+1)xy+1y^2 &\quad \text{DPF(4.3a)}\\
1x^2+2xy+1y^2 &\quad \text{OOA(2.1)}\\
x^2+2xy+y^2 &\quad \text{MId(4.9b)}
\end{aligned}$$

■

Example 11.7 – id:20151018-182202.
Simplify by expanding $(x-y)^2$

S

Solution:

$$\begin{array}{rr}
(1x - 1y)^2 & \text{MId}(4.9a) \\
(1x - 1y)(1x - 1y) & \text{PoTF}(3.9) \\
(1x - 1y)(1x - 1y) & \text{MId}(4.9a) \\
(1x + \neg 1y)(1x + \neg 1y) & \text{DOS}(4.12a) \\
1x(1x + \neg 1y) + \neg 1y(1x + \neg 1y) & \text{DPE}(4.8b) \\
1x \cdot 1x + 1x \cdot \neg 1y + \neg 1y \cdot 1x + \neg 1y \cdot \neg 1y & \text{DPE}(4.8a) \\
1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot \neg 1 \cdot y + \neg 1 \cdot y \cdot 1 \cdot x + \neg 1 \cdot y \cdot \neg 1 \cdot y & \text{JTC}(3.5) \\
1 \cdot 1 \cdot x \cdot x + 1 \cdot \neg 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot \neg 1 \cdot y \cdot y & \text{CPM}(4.6) \\
1 \cdot 1 \cdot x^2 + 1 \cdot \neg 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot \neg 1 \cdot y^2 & \text{PrCBPo}(5.3a) \\
1 \cdot x^2 + \neg 1 \cdot x \cdot y + \neg 1 \cdot x \cdot y + 1 \cdot y^2 & \text{OOM}(2.4) \\
1x^2 + \neg 1xy + \neg 1xy + 1y^2 & \text{CTJ}(3.6) \\
1x^2 + (\neg 1 + \neg 1)xy + 1y^2 & \text{DPF}(4.3a) \\
1x^2 + \neg 2xy + 1y^2 & \text{OOA}(2.1) \\
1x^2 - 2xy + 1y^2 & \text{DOS}(4.12b) \\
x^2 - 2xy + y^2 & \text{AId}(4.4b)
\end{array}$$

■

Example 11.8 – id:20151018-164638.
Simplify by expanding $(x - y)(x + y)$

S

Solution:

$$\begin{array}{rr}
(1x - 1y)(1x + 1y) & \text{MId}(4.9a) \\
(1x + \neg 1y)(1x + 1y) & \text{DOS}(4.12a) \\
1x(1x + 1y) + \neg 1y(1x + 1y) & \text{DPE}(4.8b) \\
1x \cdot 1x + 1x \cdot 1y + \neg 1y \cdot 1x + \neg 1y \cdot 1y & \text{DPE}(4.8a) \\
1 \cdot x \cdot 1 \cdot x + 1 \cdot x \cdot 1 \cdot y + \neg 1 \cdot y \cdot 1 \cdot x + \neg 1 \cdot y \cdot 1 \cdot y & \text{JTC}(3.5) \\
1 \cdot 1 \cdot x \cdot x + 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot y \cdot y & \text{CPM}(4.6) \\
1 \cdot 1 \cdot x^2 + 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot x \cdot y + \neg 1 \cdot 1 \cdot y^2 & \text{PrCBPo}(5.3a) \\
1 \cdot x^2 + 1 \cdot x \cdot y + \neg 1 \cdot x \cdot y + \neg 1 \cdot y^2 & \text{OOM}(2.4) \\
1x^2 + 1xy + \neg 1xy + \neg 1y^2 & \text{CTJ}(3.6) \\
1x^2 + \neg 1y^2 & \text{OOA}(2.1)\ \text{goto}\ \ 11.1 \\
1x^2 - 1y^2 & \text{DOS}(4.12b) \\
x^2 - y^2 & \text{MId}(4.9b)
\end{array}$$

12. Factoring Univariate Trinomials

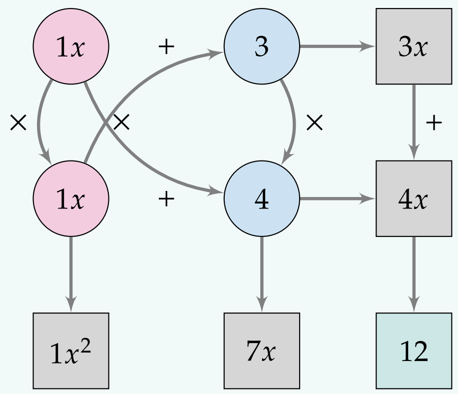
Example 12.1 – id:20151015-184212.
Simplify by factoring $x^2 + 7x + 12$

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 12.2 – id:20151016-063338.

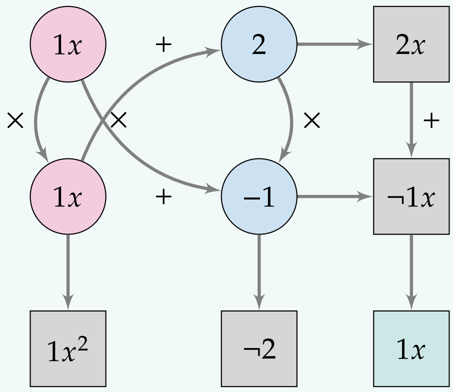
Simplify by factoring $x^2 + x - 2$

S

Solution:
Using the distributive property organizer

The factors of $(x^2 + x - 2)$ are $(x + 2)(x - 1)$

$$\begin{aligned} 1x^2 + 1x - 2 & \qquad \text{AId(4.4a)} \\ 1x^2 + 1x + \neg 2 & \qquad \text{DOS(4.12a)} \end{aligned}$$



$$\begin{aligned} (1x + 2)(1x + \neg 1) & \\ (1x + 2)(1x - 1) & \qquad \text{DOS(4.12b)} \\ (x + 2)(x - 1) & \qquad \text{MId(4.9b)} \end{aligned}$$

13. Solving Linear Equations

13.1 Power Inverse

Example 13.1 – id:20141206-102142.

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

S

Solution:

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

Example 13.2 – id:20141111-222931.

Solve the equations $x + 8 = 0$

S

Solution:

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

S

Less Steps Solution:

$$[x + 8] + \neg 8 = [0] + \neg 8 \qquad \text{SPE(4.15) + AI(4.5a)}$$
$$x = -8 \qquad \text{OOA(2.1)}$$

D

Dependencies:
example ??-20141111-190212

Example 13.3 – id:20141206-101632.

Solve the equation $x + 4 = 7$

S

Solution:

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

S

Less Steps Solution:

$$[x] + 4 + \neg 4 = [7] + \neg 4 \qquad \text{SPE(4.15)} + \text{AI(4.5a)}$$
$$x = 3 \qquad \text{OOA(2.1)}$$

Example 13.4 – id:20141206-101107.

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

S

Solution:

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

S

Less Steps Solution:

$$[x + \neg 8] + 8 = [15] + 8 \qquad \text{SPE(4.15) + AI(4.5a)}$$
$$x = 23 \qquad \text{OOA(2.1)}$$

Example 13.5 – id:20141206-102404.

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

S

Solution:

$$\frac{1}{5}[5x] = \frac{1}{5}[9] \qquad \text{SPE(4.15) + MI(4.10a)}$$
$$\frac{1}{5} \cdot [5 \cdot x] = \frac{1}{5} \cdot 9 \qquad \text{JTC(3.5)}$$
$$\left(\frac{1}{5} \cdot 5\right) \cdot x = \frac{1}{5} \cdot 9 \qquad \text{APM(4.7b)}$$
$$1 \cdot x = \frac{9}{5} \qquad \text{OOM(2.4)}$$
$$x = \frac{9}{5} \qquad \text{MId(4.9b)}$$

S

Less Steps Solution:

$$\frac{1}{5}[5x] = \frac{1}{5}[9] \qquad \text{SPE(4.15) + MI(4.10a)}$$
$$x = \frac{9}{5} \qquad \text{OOM(2.4)}$$

Example 13.6 – id:20141206-104404.

Solve the equation $ax = b$ for x.

S

Solution:

$$\frac{1}{a}\,[ax] = \frac{1}{a}\,[b] \qquad \text{SPE(4.15) + MI(4.10a)}$$
$$\frac{1}{a}\cdot(a\cdot x) = \frac{1}{a}\cdot b \qquad \text{JTC(3.5)}$$
$$\left(\frac{1}{a}\cdot a\right)\cdot x = \frac{1}{a}\cdot b \qquad \text{APM(4.7b)}$$
$$1\cdot x = \frac{b}{a} \qquad \text{OOM(2.4)}$$
$$x = \frac{b}{a} \qquad \text{MId(4.9b)}$$

Example 13.7 – id:20141206-102723.

Solve the equation $-2x = 7$ for x

S

Solution:

$$\neg 2x = 7 \qquad \text{ONeg(3.1a)}$$
$$\neg\frac{1}{2}\,[\neg 2x] = \neg\frac{1}{2}\,[7] \qquad \text{SPE(4.15) + MI(4.10b)}$$
$$\neg\frac{1}{2}\cdot(\neg 2\cdot x) = \neg\frac{1}{2}\cdot 7 \qquad \text{JTC(3.5)}$$
$$\left(\neg\frac{1}{2}\cdot\neg 2\right)\cdot x = \neg\frac{1}{2}\cdot 7 \qquad \text{APM(4.7b)}$$
$$1\cdot x = \neg\frac{7}{2} \qquad \text{OOM(2.4)}$$
$$1\cdot x = -\frac{7}{2} \qquad \text{ONeg(3.1b)}$$
$$x = -\frac{7}{2} \qquad \text{MId(4.9b)}$$

S

Less Steps Solution:

$$\neg\frac{1}{2}\,[\neg 2x] = \neg\frac{1}{2}\,[7] \qquad \text{SPE(4.15) + MI(4.10b)}$$
$$x = -\frac{7}{2} \qquad \text{OOM(2.4)}$$

Example 13.8 – id:20141111-215726.

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

S

Solution:

$$
\begin{aligned}
[2x + 5] + \neg 5 &= [0] + \neg 5 && \text{SPE(4.15) + AI(4.5a)} \\
2x + (5 + \neg 5) &= 0 + \neg 5 && \text{APA(4.2a)} \\
2x + 0 &= \neg 5 && \text{OOA(2.1)} \\
2x &= \neg 5 && \text{AId(4.4a)} \\
\frac{1}{2}[2x] &= \frac{1}{2}[\neg 5] && \text{SPE(4.15) + MI(4.10a)} \\
\frac{1}{2} \cdot 2 \cdot x &= \frac{1}{2} \cdot \neg 5 && \text{JTC(3.5)} \\
\left(\frac{1}{2} \cdot 2\right) \cdot x &= \frac{1}{2} \cdot \neg 5 && \text{APM(4.7a)} \\
1 \cdot x &= \frac{\neg 5}{2} && \text{OOM(2.4)} \\
1x &= -\frac{5}{2} && \text{ONeg(3.1b)} \\
x &= -\frac{5}{2} && \text{MId(4.9b)}
\end{aligned}
$$

S

Less Steps Solution:

$$
\begin{aligned}
[2x + 5] + \neg 5 &= [0] + \neg 5 && \text{SPE(4.15) + AI(4.5a)} && (13.1) \\
2x &= \neg 5 && \text{OOA(2.1)} && (13.2) \\
\frac{1}{2}[2x] &= \frac{1}{2}[\neg 5] && \text{SPE(4.15) + MI(4.10a)} && (13.3) \\
x &= -\frac{5}{2} && \text{OOM(2.4)} && (13.4)
\end{aligned}
$$

D

Dependencies:
example ??-20141111-192213 ▪

Example 13.9 – id:20151020-180416.
Solve the equation $24\,\text{m} = 2x + y$ for y

S

Solution:

$$
\begin{aligned}
\neg 2x + [\mathbf{24\,m}] &= \neg 2x\,[\mathbf{2x + y}] && \text{AI}(4.5a), \text{SPE}(4.15)\\
\neg 2x + 24\,\mathrm{m} &= (\neg 2x + 2x) + y && \text{APA}(4.2a)\\
\neg 2x + 24\,\mathrm{m} &= 0 + y && \text{OOA}(2.1)\\
\neg 2x + 24\,\mathrm{m} &= y && \text{AId}(4.4b)\\
-2x + 24\,\mathrm{m} &= y && \text{ONeg}(3.1b)\\
y &= -2x + 24\,\mathrm{m} && \text{SyPE}(4.16a)
\end{aligned}
$$

D

Dependencies:example 23.1-20151020-171605

Example 13.10 – id:20151021-060347.
Solve $-4x + 24\,\mathrm{m} = 0$ for x, where m is the unit length for meters.

S

Solution:

$$
\begin{aligned}
\neg 4x + 24\,\mathrm{m} &= 0 && \text{ONeg}(3.1a)\\
[\mathbf{\neg 4x + 24\,m}] + \neg 24\,\mathrm{m} &= [\mathbf{0}] + \neg 24\,\mathrm{m} && \text{AI}(4.5a), \text{SPE}(4.15)\\
\neg 4x + (24\,\mathrm{m} + \neg 24\,\mathrm{m}) &= [\mathbf{0}] + \neg 24\,\mathrm{m} && \text{APA}(4.2b)\\
\neg 4x + 0 &= 0 + \neg 24\,\mathrm{m} && \text{OOA}(2.1)\\
\neg 4x &= \neg 24\,\mathrm{m} && \text{AId}(4.4b)\\
\frac{1}{\neg 4}\,[\mathbf{\neg 4x}] &= \frac{1}{\neg 4}\,[\mathbf{\neg 24\,m}] && \text{MI}(4.5a), \text{SPE}(4.15)\\
\left(\frac{1}{\neg 4}\cdot 4\right)x &= (dfrac1\neg 4\cdot\neg 24)\ \mathrm{m} && \text{APM}(4.7b)\\
\frac{4}{4}x &= \frac{24}{4}\,\mathrm{m} && \text{OOM}(2.4)\\
1x &= 6\,\mathrm{m} && \text{RF}(8.1.1)\\
1x &= 6\,\mathrm{m} && \text{ONeg}(3.1b)\\
x &= 6\,\mathrm{m} && \text{MId}(4.9b)
\end{aligned}
$$

D

Dependencies:example 23.1-20151020-171605

example 19.1-20151021-061907

Example 13.11 – id:20151015-104754.
Solve the equation $2ax + b = 0$ for x.

S

Solution:

$$
\begin{aligned}
[2ax + b] + \neg b &= [0] + \neg b && \text{AI(4.5a), SPE(4.15)} \\
2ax + (b + \neg b) &= 0 + \neg b && \text{APA(4.2b)} \\
2ax + 0 &= 0 + \neg b && \text{OOA(2.1)} \\
2ax &= \neg b && \text{AId(4.4a)} \\
\frac{1}{2a}[2ax] &= \frac{1}{2a}[\neg b] && \text{MI(4.5a), SPE(4.15)} \\
\frac{1}{2a} \cdot (2ax) &= \frac{1}{2a} \cdot (\neg b) && \text{JTC(3.5)} \\
\left(\frac{1}{2a} \cdot 2a\right) \cdot x &= \frac{1}{2a} \cdot \neg b && \text{APA(4.2a)} \\
\left(\frac{1}{2a} \cdot \frac{2a}{1}\right) x &= \frac{1}{2a} \cdot \frac{negb}{1} && \text{MId(4.9a)} \\
\frac{2a}{2a} \cdot x &= \frac{\neg b}{2a} && \text{OOM(2.4)} \\
1 \cdot x &= \frac{\neg b}{2a} x && = \frac{\neg b}{2a} \qquad \text{MId(4.9b)} \\
x &= -\frac{b}{2a} && \text{ONeg(3.1b)}
\end{aligned}
$$

D

Dependencies:example 20.1-20151008-110208

14. Solving Quadratic Equations

14.1 Mutiliplicative Inverse

Example 14.1 – id:20141107-131748.

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

S

Solution:

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

■

Example 14.2 – id:20151012-192313.

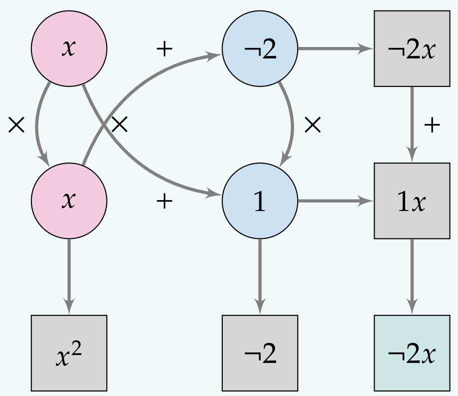
Solve the equation $6x^2 - 6x - 12 = 0$

S

Solution:

$$\begin{aligned}
6x^2 + \neg 6x + \neg 12 &= 0 && \text{DOS(4.12a)}\\
6(1x^2 \neg 1x + \neg 2) &= 0 && \text{DPF(4.3b)}
\end{aligned}$$

Using the factor orgnanizer,



Solving the linear equations using ZPr (4.11a)

$$
\begin{aligned}
x_1 + \neg 2 &= 0 && \text{Case I}\\
[x_1 + \neg 2] + 2 &= [0] + \neg 2 && \text{AI(4.5a), SPE(4.15)}\\
x_1 + (\neg 2 + 2) &= 0 + \neg 2 && \text{APA(4.2a)}\\
x_1 + 0 &= \neg 2 && \text{OOA(2.1)}\\
x_1 &= \neg 2 && \text{AId(4.4b)}\\
x_1 &= -2 && \text{ONeg(3.1b)}
\end{aligned}
$$

$$
\begin{aligned}
x_2 + 1 &= 0 && \text{Case II}\\
[x_2 + 1] + \neg 1 &= [0] + \neg 1 && \text{AI(4.5a), SPE(4.15)}\\
x_2 + (1 + \neg 1) &= 0 + \neg 1 && \text{APA(4.2a)}\\
x_2 + 0 &= \neg 2 && \text{OOA(2.1)}\\
x_2 &= \neg 2 && \text{AId(4.4b)}\\
x_2 &= -2 && \text{ONeg(3.1b)}
\end{aligned}
$$

D

Dependencies:example 19.2-20151012-190708

14.2 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 $x =$ some value(s), we first want the coefficient factor a to be equal to 1.

$$\begin{aligned}
\frac{1}{a}\left[ax^2 + bx + c\right] &= \frac{1}{a}\,[0] && \text{SPE(4.15) + MI(4.10a)}\\
\frac{1}{a}\cdot ax^2 + \frac{1}{a}\cdot bx + \frac{1}{a}\cdot c &= \frac{1}{a}\,[0] && \text{DPE(4.8a)}\\
\frac{1}{a}\cdot a\cdot x^2 + \frac{1}{a}\cdot b\cdot x + \frac{1}{a}\cdot c &= \frac{1}{a}\,[0] && \text{JTC(3.5)}\\
x^2 + \frac{b}{a}\cdot x + \frac{c}{a} &= 0 && \text{OOM(2.4)}\\
x^2 + \frac{b}{a}x + \frac{c}{a} &= 0 && \text{CTJ(3.6)}
\end{aligned}$$

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 = some value, so the next step is focused on removing the $\frac{c}{a}$ summand.

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

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 $k = m \cdot m$.

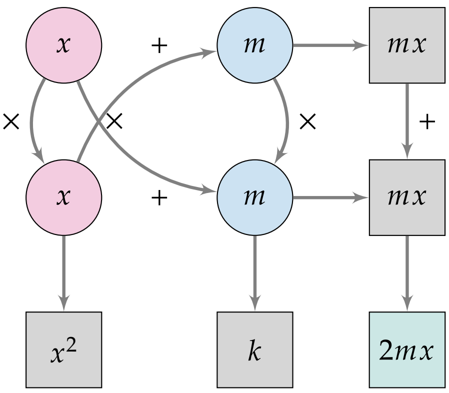


Figure 14.1: The Organization of the Distributive Property

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), $\left[x^2 + \frac{b}{a}x\right] + k = \left[\neg\frac{c}{a}\right] + k$.

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.

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

Solving for m,

$$\begin{aligned}
2mx &= \frac{b}{a}x \\
\frac{1}{2}\left[\mathbf{2mx}\right] &= \frac{1}{2}\left[\mathbf{\frac{b}{a}x}\right] && \text{SPE(4.15)} + \text{MI(4.10a)} \\
\left(\frac{1}{2}\cdot 2\right)mx &= \left(\frac{1}{2}\frac{b}{a}\right)x && \text{APA(4.2a)} \\
1mx &= \frac{b}{2a}x && \text{OOM(2.4)} \\
mx &= \frac{b}{2a}x && \text{MId(4.9b)} \\
\left[\mathbf{mx}\right]\frac{1}{x} &= \left[\mathbf{\frac{b}{2a}x}\right]\frac{1}{x} && \text{SPE(4.15)} + \text{MI(4.10a)} \\
m\left(x\cdot\frac{1}{x}\right) &= \frac{b}{2a}\left(x\cdot\frac{1}{x}\right) && \text{APM(4.7b)} \\
m\cdot 1 &= \frac{b}{2a}\cdot 1 && \text{OOM(2.4)} \\
m &= \frac{b}{2a} && \text{MId(4.9b)}
\end{aligned}$$

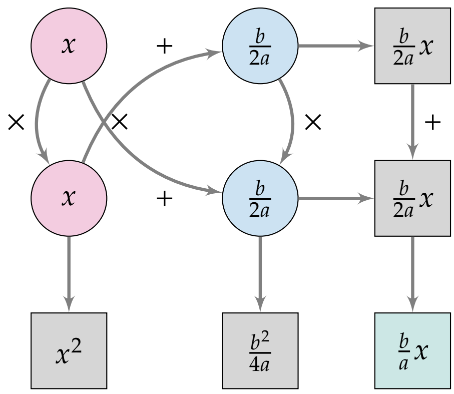


Figure 14.2: The Organization of the Distributive Property

$$\left[x^2 + \frac{b}{a}x\right] + \left(\frac{b}{2a}\right)^2 = \left[\neg\frac{c}{a}\right] + \left(\frac{b}{2a}\right)^2 \qquad \text{SPE(4.15) + Completing the Square}$$

$$x^2 + \frac{b}{a}x + \left(\frac{b}{2a}\right)^2 = \neg\frac{c}{a} + \left(\frac{b}{2a}\right)^2 \qquad \text{APA(4.2a)}$$

$$\left(x + \frac{b}{2a}\right)\left(x + \frac{b}{2a}\right) = \neg\frac{c}{a} + \left(\frac{b}{2a}\right)^2 \qquad \text{DPF(4.3b)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{c}{a} + \left(\frac{b}{2a}\right)^2 \qquad \text{PoTF(3.9)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{c}{a} + \frac{(b)^2}{(2a)^2} \qquad \text{PoQPo(5.5a)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{c}{a} + \frac{b^2}{2^2a^2} \qquad \text{PoPrPo(5.6a)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{c}{a} + \frac{b^2}{4a^2} \qquad \text{OOE(2.6)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{c}{a} \cdot \frac{4a}{4a} + \frac{b^2}{4a^2} \qquad \text{MId(4.9a)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{c \cdot 4 \cdot a}{a \cdot 4 \cdot a} + \frac{b^2}{4a^2} \qquad \text{JTC(3.5)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{4 \cdot a \cdot c}{4 \cdot a \cdot a} + \frac{b^2}{4a^2} \qquad \text{CPM(4.6)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{4 \cdot a \cdot c}{4 \cdot a^2} + \frac{b^2}{4a^2} \qquad \text{PrCBPo(5.3a)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \neg\frac{4ac}{4a^2} + \frac{b^2}{4a^2} \qquad \text{CTJ(3.6)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \frac{\neg 4ac + b^2}{4a^2} \qquad \text{CD(2.7a)}$$

$$\left(x + \frac{b}{2a}\right)^2 = \frac{b^2 + \neg 4ac}{4a^2} \qquad \text{CPM(4.6)}$$

$$\left[\left(x + \frac{b}{2a}\right)^2\right]^{\frac{1}{2}} = \pm\left[\frac{b^2 + \neg 4ac}{4a^2}\right]^{\frac{1}{2}} \qquad \text{SPE(4.15)}$$

$$x + \frac{b}{2a} = \pm\left[\frac{b^2 + \neg 4ac}{4a^2}\right]^{\frac{1}{2}} \qquad \text{PoPrPo(5.6a)}$$

$$x + \frac{b}{2a} = \pm\frac{\left[b^2 + \neg 4ac\right]^{\frac{1}{2}}}{\left[4a^2\right]^{\frac{1}{2}}} \qquad \text{PoQPo(5.5a)}$$

$$x + \frac{b}{2a} = \pm\frac{\left[b^2 + \neg 4ac\right]^{\frac{1}{2}}}{4^{\frac{1}{2}}a} \qquad \text{PoPrPo(5.6a)}$$

$$x + \frac{b}{2a} = \pm\frac{\left[b^2 + \neg 4ac\right]^{\frac{1}{2}}}{2a} \qquad \text{OOE(2.6)}$$

$$x + \frac{b}{2a} = \pm\frac{\sqrt{b^2 - 4ac}}{2a} \qquad \text{RTPo(3.12)}$$

$$
\begin{aligned}
\left[x + \frac{b}{2a}\right] + \neg\frac{b}{2a} &= \left[\pm\frac{\sqrt{b^2 - 4ac}}{2a}\right] + \neg\frac{b}{2a} && \text{SPE(4.15)} + \text{AI(4.5a)} \\
x + \left(\frac{b}{2a} + \neg\frac{b}{2a}\right) &= \pm\frac{\sqrt{b^2 - 4ac}}{2a} + \neg\frac{b}{2a} && \text{APA(4.2b)} \\
x + \left(\frac{b}{2a} + \neg\frac{b}{2a}\right) &= \neg\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a} && \text{CPM(4.6)} \\
x + 0 &= \neg\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a} && \text{OOA(2.1)} \\
x &= \neg\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a} && \text{AId(4.4b)} \\
x &= \frac{\neg b \pm \sqrt{b^2 - 4ac}}{2a} && \text{CD(2.7a)} \\
x &= \frac{\neg b \pm \sqrt{b^2 - 4ac}}{2a} && \text{DOS(4.12b)} \\
x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} && \text{ONeg(3.1b)}
\end{aligned}
$$

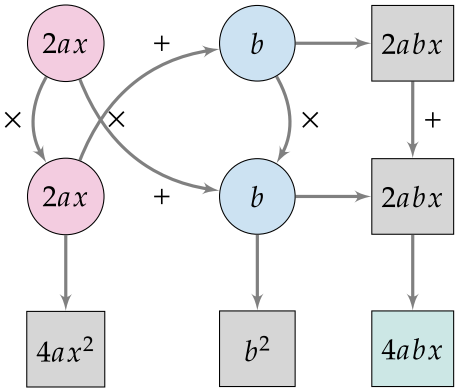
■

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.

$$
\begin{aligned}
ax^2 + bx + c &= 0 \\
4a\left[ax^2 + bx + c\right] &= 4a\,[0] && \text{SPE(4.15)} \\
4ax^2 + 4abx + 4ac &= 4a(0) && \text{DPE(4.8a)} \\
4ax^2 + 4abx + 4ac &= 0 && \text{OOM(2.4)} \\
\left[4ax^2 + 4abx + 4ac\right] + \neg 4ac &= [0] + \neg 4ac && \text{AI(4.5a), SPE(4.15)} \\
4ax^2 + 4abx + (4ac + \neg 4ac) &= 0 + \neg 4ac && \text{APA(4.2a)} \\
4ax^2 + 4abx + 0 &= 0 + \neg 4ac && \text{OOA(2.1)} \\
4ax^2 + 4abx &= \neg 4ac && \text{AId(4.4b)}
\end{aligned}
$$

Completing the square



$$
\begin{aligned}
\left[4ax^2 + 4abx\right] + b^2 &= \left[-4ac\right] + b^2 && \text{SPE(4.15)}\\
4ax^2 + 4abx + b^2 &= b^2 + \neg 4ac && \text{CPA(4.1)}\\
(2ax + b)(2ax + b) &= b^2 + \neg 4ac && \text{DPF(4.3a)}\\
(2ax + b)^2 &= b^2 + \neg 4ac && \text{PoTF(3.9)}\\
\left[(2ax + b)^2\right]^{\frac{1}{2}} &= \pm\left[b^2 + \neg 4ac\right]^{\frac{1}{2}} && \text{SPE(4.15)}\\
2ax + b &= \pm(b^2 + \neg 4ac)^{\frac{1}{2}} && \text{PoPo(5.1a)}\\
2ax + b &= \pm\sqrt{b^2 + \neg 4ac} && \text{PoTR(\textbf{??})}\\
\left[2ax + b\right] + \neg b &= \left[\pm\sqrt{b^2 + \neg 4ac}\right] + \neg b && \text{AI(4.5a), SPE(4.15)}\\
(2ax + b) + \neg b &= \neg b \pm \sqrt{b^2 + \neg 4ac} && \text{CPA(4.1)}\\
2ax + (b + \neg b) &= \neg b \pm \sqrt{b^2 + \neg 4ac} && \text{APA(4.2b)}\\
2ax + 0 &= \neg b \pm \sqrt{b^2 + \neg 4ac} && \text{OOA(2.1)}\\
2ax &= \neg b \pm \sqrt{b^2 + \neg 4ac} && \text{AId(4.4b)}\\
\frac{1}{2a}\left[2ax\right] &= \frac{1}{2a}\left[\neg b \pm \sqrt{b^2 + \neg 4ac}\right] && \text{MI(4.5a), SPE(4.15)}\\
\left(\frac{1}{2a} \cdot 2a\right) x &= \frac{1}{2a}\left(\neg b \pm \sqrt{b^2 + \neg 4ac}\right) && \text{APM(4.7a)}\\
\frac{2a}{2a} x &= \frac{\neg b \pm \sqrt{b^2 + \neg 4ac}}{2a} && \text{OOM(2.4)}\\
1x &= \frac{\neg b \pm \sqrt{b^2 + \neg 4ac}}{2a} && \text{RF(8.1.1)}\\
1x &= \frac{\neg b \pm \sqrt{b^2 - 4ac}}{2a} && \text{DOS(4.12b)}\\
1x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} && \text{ONeg(3.1b)}\\
x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} && \text{MId(4.9b)}
\end{aligned}
$$

∎

IV

Functions

15. Functions

Property 15.0.1 – Function Value Argument Substitution (FVAS).

$$f(a) \tag{15.1a}$$

Example 15.1 – id:20151012-201647.
Find $f(2)$ given $f(x) = 2x^3 - 3x^2 - 12x + 1$

S

Solution:

$f(x) = 2x^3 + \neg 3x^2 + \neg 12x + 1$	DOS(4.12a)
$f(2) = 2\,[2]^3 + \neg 3\,[2]^2 + \neg 12\,[2] + 1$	SPE(4.15)
$f(2) = 2(8) + \neg 3(4) + \neg 12(2) + 1$	OOE(2.6)
$f(2) = 16 + \neg 12 + \neg 24 + 1$	OOM(2.4)
$f(2) = -19$	OOA(2.1)

D

Dependencies:example 19.2-20151012-190708

Example 15.2 – id:20151012-203549.
Find $f(-1)$ given $f(x) = 2x^3 - 3x^2 - 12x + 1$

S

Solution:

$$
\begin{aligned}
f(x) &= 2x^3 + \neg 3x^2 + \neg 12x + 1 && \text{DOS(4.12a)}\\
f(\neg 1) &= 2\left[\neg \mathbf{1}\right]^3 + \neg 3\left[\neg \mathbf{1}\right]^2 + \neg 12\left[\neg \mathbf{1}\right] + 1 && \text{SPE(4.15)}\\
f(\neg 1) &= 2(\neg 1) + \neg 3(1) + \neg 12(\neg 1) + 1 && \text{OOE(2.6)}\\
f(\neg 1) &= \neg 2 + \neg 3 + 12 + 1 && \text{OOM(2.4)}\\
f(\neg 1) &= 8 && \text{OOA(2.1)}
\end{aligned}
$$

D

Dependencies:example 19.2-20151012-190708

15.1 Inverse Functions

15.2 Inverses

Property 15.2.1 – Cosine Inverse (ArcCos).

$$\cos^{-1}(\cos\theta) = \theta \tag{15.2a}$$

Property 15.2.2 – Sine Inverse (ArcSin).

$$\sin^{-1}(\sin\theta) = \theta \tag{15.3a}$$

Property 15.2.3 – Tangent Inverse (ArcTan).

$$\tan^{-1}(\tan\theta) = \theta \tag{15.4a}$$

Property 15.2.4 – Exponential Inverse (EI).

$$\log_a(a^x) = x \tag{15.5a}$$

Property 15.2.5 – Logarithmic Inverse (LI).

$$a^{\log_a x} = x \tag{15.6a}$$

Property 15.2.6 – Power Inverse (PoI).

$$(b^m)^{\frac{1}{m}} = b \tag{15.7a}$$

V

Differential Calculus

16. Derivative by First Principles

16.1 Limit of the Difference Quotient

Definition 16.1.1 – Derivative. The derivative of a function $f(x)$ with respect to the variable x is defined as

$$f'(x) \equiv \lim_{\Delta x \to 0} \underbrace{\frac{f(x+\Delta x)-f(x)}{\Delta x}}_{\text{Difference Quotient}} \tag{16.1}$$

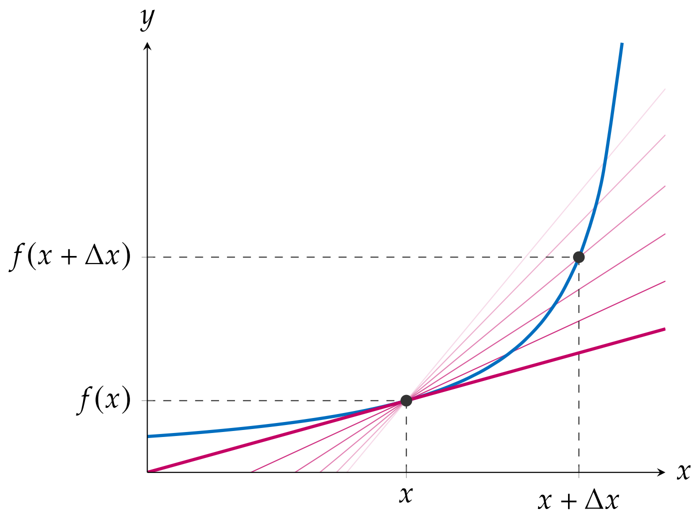


Figure 16.1: [3]

Example 16.1 – id:20141219-212546.

Differentiate the function $f(x) = 5$

S

Solution:

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

$$f'(x) = \lim_{\Delta x \to 0} \frac{5\,[x + \Delta x]^0 - 5\,[x]^0}{\Delta x} \qquad \text{SPE(4.15)\&DBFP(16.1)}$$

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

$$f'(x) = \lim_{\Delta x \to 0} 0 \qquad \text{OOM(2.4)}$$

$$f'(x) = 0$$

■

17. Derivative Rules

17.1 Derivative of a Monomial Functions

Example 17.1 – id:20141124-153017.

Differentiate $f(x) = -3$

S

Solution:

$f'(x) = [-3]'$ SPE(4.15)
$f'(x) = 0$ DC(7.1)

D

Dependencies:
example 17.3-20141124-152503

Example 17.2 – 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 17.2-20141124-141850
example 17.3-20141124-152503

17.2 Derivative of Polynomial Functions

Example 17.3 – id:20141124-152503.

Differentiate $f(x) = x^2 - 3$

S

Solution:

$$
\begin{aligned}
f(x) &= x^2 + \neg 3 && \text{DOS(4.12a)}\\
f'(x) &= \left[x^2 + \neg 3\right]' && \text{SPE(4.15)}\\
f'(x) &= \left[x^2\right]' + [\neg 3]' && \text{DS(7.7)}\\
f'(x) &= \left[x^2\right]' + 0 && \text{DC(7.1)}\\
f'(x) &= \left[x^2\right]' && \text{AId(4.4a)}\\
f'(x) &= 2x && \text{DPo(7.5) goto 17.2}
\end{aligned}
$$

S

Less Steps Solution:

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

D

Dependencies:
example 17.15-20141124-205219

Example 17.4 – id:20151015-155838.
Differentiate $y = x^3 + 1$

S

Solution:

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

D

Dependencies:example 17.17-20151015-153507

Example 17.5 – id:20151011-195002.
Differentiate $f(x) = 2x^2 + 3x + 7$

S

Solution:

$$\begin{aligned}
[f'(x)]' &= [2x^2 + 3x + 7]' && \text{SPE}(4.15)\\
f'(x) &= [2x^2]' + [3x]' + [7]' && \text{DS}(7.7)\\
f'(x) &= 2\,[x^2]' + 3\,[x]' + [7]' && \text{DCM}(7.3)\\
f'(x) &= 2\,[x^2]' + 3\,[x]' + 0 && \text{DC}(7.1)\\
f'(x) &= 2\,[x^2]' + 3\,[x]' && \text{AId}(4.4a)\\
f'(x) &= 2(2x) + 3 && \text{DPo}(7.5)\\
f'(x) &= 4x + 3 && \text{OOM}(2.4)
\end{aligned}$$

D

Dependencies:example 18.1-20151011-154209

Example 17.6 – id:20151021-054427.
Differentiate $A(x) = -2x^2 + 25$.

S

Solution:

$$A(x) = \neg 2x^2 + 24x \qquad \text{ONeg}(3.1a)$$
$$[A(x)]' = \left[\neg 2x^2 + 24x\right]' \qquad \text{SPE}(4.15)$$
$$A'(x) = \left[\neg 2x^2\right]' + [24x]' \qquad \text{DS}(7.7)$$
$$A'(x) = \neg 2\left[x^2\right]' + 24\,[x]' \qquad \text{DCM}(7.3)$$
$$A'(x) = \neg 2(2x^1) + 24(1) \qquad \text{DPo}(7.5)$$
$$A'(x) = \neg 4x^1 + 24 \qquad \text{OOM}(2.4)$$
$$A'(x) = -4x + 24 \qquad \text{ONeg}(3.1b)$$

D

Dependencies:example 23.1-20151020-171605

example 19.1-20151021-061907

Example 17.7 – id:20141128-151834.

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

S

Solution:

$$f(x) = 3x^2 + \neg 6x + 4 \qquad \text{DOS}(4.12a)$$
$$f'(x) = \left[3x^2 + \neg 6x + 4\right]' \qquad \text{SPE}(4.15)$$
$$f'(x) = \left[3x^2\right]' + [6x]' + [4]' \qquad \text{DS}(7.7)$$
$$f'(x) = \left[3x^2\right]' + [6x]' + 0 \qquad \text{DC}(7.1)$$
$$f'(x) = \left[3x^2\right]' + [6x]' \qquad \text{AId}(4.4a)$$
$$f'(x) = 3\left[x^2\right]' + 6\,[x]' \qquad \text{DCM}(7.3)$$
$$f'(x) = 3\,(2x) + 6\,(1) \qquad \text{DPo}(7.5)$$
$$f'(x) = 6x + 6 \qquad \text{OOM}(2.4)$$

S

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

Example 17.8 – id:20141209-144203.

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

S

Solution:

$$
\begin{aligned}
f'(x) &= \left[x^2(2x+4)\right]' && \text{SPE(4.15)}\\
f'(x) &= \left[x^2\right]'(2x+4) + x^2\left[2x+4\right]' && \text{DPr(7.11)}\\
f'(x) &= \left[x^2\right]'(2x+4) + x^2\left[2x\right] + \left[4\right]' && \text{DS(7.7)}\\
f'(x) &= \left[x^2\right]'(2x+4) + x^2\cdot 2\left[x\right] + \left[4\right]' && \text{DCM(7.3)}\\
f'(x) &= 2x(2x+4) + x^2\cdot 2\cdot 1 + \left[4\right]' && \text{DPo(7.5)}\\
f'(x) &= 2x(2x+4) + x^2\cdot 2\cdot 1 + 0 && \text{DC(7.1)}\\
f'(x) &= 6x^2 + 8x && \text{simplify goto 10.38}
\end{aligned}
$$

■

Example 17.9 – id:20141209-142321.

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

S

Solution:

$$
\begin{aligned}
f'(x) &= \left[x^2\cos(x)\right]' && \text{SPE(4.15)}\\
f'(x) &= \left[x^2\right]'\cos(x) + x^2\left[\cos(x)\right]' && \text{DPr(7.11)}\\
f'(x) &= 2x\cos(x) + x^2\left[\cos(x)\right]' && \text{DPo(7.5)}\\
f'(x) &= 2x\cos(x) + x^2(-1\sin(x)) && \text{DCos(7.19)}\\
f'(x) &= 2x\cos(x) - x^2\sin x && \text{OOM(2.4)}
\end{aligned}
$$

■

Example 17.10 – id:20150910-115935.

Differentiate $f(x) = \sin(x)\cos(x)$

S

Solution:

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

■

Example 17.11 – id:20141209-151354.

Differentiate $f(x) = \sin(x)\sin(x)$

S

Solution:

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

■

Example 17.12 – 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,

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

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

$$y = \ln(u) \qquad u = 3x$$
$$\frac{dy}{du} = \frac{1}{u} \qquad \frac{du}{dx} = 3$$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \qquad \text{DComp(7.16)}$$
$$\frac{dy}{dx} = \frac{1}{u} \cdot \frac{du}{dx} \qquad \text{DNL(7.31)}$$
$$\frac{dy}{dx} = \frac{1}{u} \cdot 3 \qquad \text{DPo(7.5)}$$
$$\frac{dy}{dx} = \frac{1}{3x} \cdot 3$$
$$\frac{dy}{dx} = \frac{3}{3x} \qquad \text{OOM(2.4)}$$
$$\frac{dy}{dx} = \frac{1}{x}$$

D

Dependencies:
example 17.15-20141124-205219

Example 17.13 – 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,

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

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

$$y = \ln(u) \qquad u = 3x^2 - 6x + 4$$
$$\frac{dy}{du} = \frac{1}{u} \qquad \frac{du}{dx} = 6x - 6 \qquad \text{goto } 17.7$$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \qquad \text{DComp(7.16)}$$
$$\frac{dy}{dx} = \frac{1}{u} \cdot \frac{du}{dx} \qquad \text{DNL(7.31)}$$
$$\frac{dy}{dx} = \frac{1}{u} \cdot (6x - 6) \qquad \text{DPo(7.5)}$$
$$\frac{dy}{dx} = \frac{1}{3x^2 - 6x + 4} \cdot (6x - 6)$$
$$\frac{dy}{dx} = \frac{6x - 6}{3x^2 - 6x + 4} \qquad \text{OOM(2.4)}$$

■

Example 17.14 – 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,

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

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

$$y = \ln(u) \qquad u = \cos x$$
$$\frac{dy}{du} = \frac{1}{u} \qquad \frac{du}{dx} = -\sin x$$

$$\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx} \qquad \text{DComp(7.16)}$$
$$\frac{dy}{dx} = \frac{1}{u} \cdot \frac{du}{dx} \qquad \text{DNL(7.31)}$$
$$\frac{dy}{dx} = \frac{1}{u} \cdot -\sin x \qquad \text{DPo(7.5)}$$
$$\frac{dy}{dx} = \frac{1}{\cos x} \cdot -\sin x$$
$$\frac{dy}{dx} = \frac{-\sin x}{\cos x} \qquad \text{OOM(2.4)}$$
$$\frac{dy}{dx} = -\tan x$$

Example 17.15 – id:20141124-205219.

Differentiate $y = \left(x^2 - 1\right)\ln(3x)$

S

Solution:

$$
\begin{aligned}
y' &= \left[x^2 - 3\right]' \cdot \ln x + \left(x^2 - 3\right) \cdot [\ln 3x]' && \text{DPr(7.11)}\\
y' &= 2x \cdot \ln x + \left(x^2 - 3\right) \cdot [\ln 3x]' && \text{differentiate goto } 17.3\\
y' &= 2x \cdot \ln x + \left(x^2 - 3\right) \cdot \frac{1}{x} && \text{differentiate goto } 17.12\\
y' &= 2x \cdot \ln x + \frac{x^2 - 3}{x} && \text{OOM(2.4)}\\
y' &= 2x^2 \ln x + \frac{x^2 - 3}{x} && \text{JTC(3.5)}\\
y' &= \frac{2x^2 \ln x + \left(x^2 - 3\right)}{x} && \text{OOA(2.1)}
\end{aligned}
$$

17.3 Derivative of a Quotient

Example 17.16 – id:20151015-165037.

Differentiate $y = \dfrac{\sin x}{e^x}$

S

Solution:

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

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\frac{\mathrm{d}}{\mathrm{d}x}\left[\sin x\right]e^x - \sin x \frac{\mathrm{d}}{\mathrm{d}x}\left[e^x\right]}{\left[e^x\right]^2} \qquad \text{DQ(??)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\frac{\mathrm{d}}{\mathrm{d}x}\left[\sin x\right]e^x - \sin x \frac{\mathrm{d}}{\mathrm{d}x}\left[e^x\right]}{e^{2x}} \qquad \text{PoPo(5.1a)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\cos x e^x - \sin x \frac{\mathrm{d}}{\mathrm{d}x}\left[e^x\right]}{e^{2x}} \qquad \text{DSin(7.18)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\cos x e^x - \sin x e^x}{e^{2x}} \qquad \text{DExp(7.34)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{e^x(\cos x - \sin x)}{e^{2x}} \qquad \text{DPF(4.3b)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{e^x(\cos x - \sin x)}{e^x e^x} \qquad \text{PrCBPo(5.3b)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\cancel{e^x}(\cos x - \sin x)}{\cancel{e^x}e^x} \qquad \text{MId(4.9a)}$$

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{\cos x - \sin x}{e^x}$$

■

17.4 Derivative of a Rational Function

Example 17.17 – id:20151015-153507.

Differentiate $f(x) = \dfrac{x^3+1}{x^2}$

S

Solution:

Method 1: Derivative of a quotient

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

$$f'(x) = \frac{\left[x^3+1\right]'(x^2) + \neg 1\left((x^3+1)\left[x^2\right]'\right)}{\left[x^2\right]^2} \qquad \text{DQ(??)}$$

$$f'(x) = \frac{(3x^2)(x^2)\neg 1\left((x^3+1)\left[x^2\right]'\right)}{\left[x^2\right]^2} \qquad \text{differentiate goto 17.4}$$

$$f'(x) = \frac{(3x^2)(x^2)\neg 1\left((x^3+1)(2x)\right)}{\left[x^2\right]^2} \qquad \text{differentiate goto 17.2}$$

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

■

18. Equations of Tangent & Secant Lines

18.1 Essential Questions

Essential Questions 18.1

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 $x = a$?

18.2 Finding the Equation of the Tangent Line

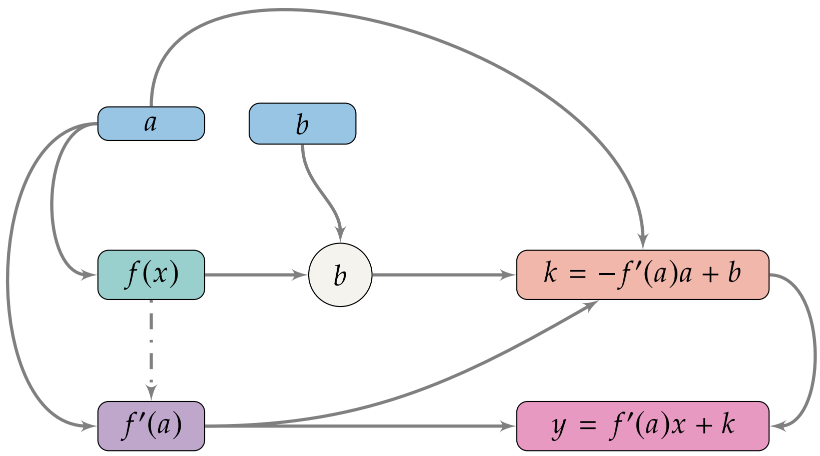


Figure 18.1: Finding the Equation of a Tangent Line Workflow

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 18.1 – 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 $f(x)$

$$f'(x) = 4x + 3 \text{ goto } 17.5$$

Evaluate the derivative at $x = 2$

$$\begin{aligned} f'(2) &= 4\,[2] + 3 && \text{SPE(4.15)} \\ f'(2) &= 8 + 3 && \text{OOM(2.4)} \\ f'(2) &= 11 && \text{OOA(2.1)} \end{aligned}$$

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

$$\begin{aligned} y &= f'(x)x + k && \\ [21] &= [11]\,[2] + k && \text{SPE(4.15)} \\ 21 &= 22 + k && \text{OOM(2.4)} \\ \neg 22 + [21] &= \neg 22 + [22 + k] && \text{SPE+AI} \\ \neg 22 + 21 &= (\neg 22 + 22) + k && \text{APA(4.2a)} \\ \neg 1 &= 0 + k && \text{OOA(2.1)} \\ \neg 1 &= k && \text{AId(4.4a)} \\ -1 &= k && \text{ONeg(3.1b)} \\ k &= -1 && \text{SyPE(4.16a)} \end{aligned}$$

The equation of the tangent line is

$$\begin{aligned} y &= f'(2)x + k && \\ y &= 11x - 1 && \text{SPE(4.15)} \end{aligned}$$

■

Example 18.2 – 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 $f(x)$

$$
\begin{aligned}
[f(x)]' &= [e^{3x}]' && \text{SPE(4.15)}\\
f'(x) &= [3x]'[e^{3x}]' && \text{DCF(7.15)}\\
f'(x) &= 3[x]'[e^{3x}]' && \text{DCM(7.3)}\\
f'(x) &= 3\cdot 1[e^{3x}]' && \text{DPo(7.5)}\\
f'(x) &= 3[e^{3x}]' && \text{OOM(2.4)}\\
f'(x) &= 3e^{3x} && \text{DExp(7.33)}
\end{aligned}
$$

Evaluate the derivative at $x = 2$

$$
\begin{aligned}
f'(2) &= 3e^{3[2]} && \text{SPE(4.15)}\\
f'(2) &= 3e^{6} && \text{OOM(2.4)}
\end{aligned}
$$

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

$$
\begin{aligned}
y &= f'(x)x + k && \\
[e^2] &= [3e^6][2] + k && \text{SPE(4.15)}\\
e^2 &= 3\cdot e^6\cdot 2 + k && \text{JTC(3.5)}\\
e^2 &= 3\cdot 2\cdot e^6 + k && \text{CPM(4.6)}\\
e^2 &= 6\cdot e^6 + k && \text{OOM(2.4)}\\
e^2 &= 6e^6 + k && \text{CTJ(3.6)}\\
\neg 6e^6 + [e^2] &= \neg 6e^6 + [6e^6 + k] && \text{AI(4.5a), SPE(4.15)}\\
e^2(\neg 6e^4 + 1) &= \neg 6e^6 + [6e^6 + k] && \text{DPF(4.3b)}\\
\neg 6e^6 + e^2 &= (\neg 6e^6 + 6e^6) + k && \text{APA(4.2a)}\\
e^2(\neg 6e^4 + 1) &= 0 + k && \text{OOA(2.1)}\\
e^2(\neg 6e^4 + 1) &= k && \text{AId(4.4b)}\\
e^2(-6e^4 + 1) &= k && \text{ONeg(3.1b)}
\end{aligned}
$$

The equation of the tangent line, L is

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

■

19. First Derivative Test

Example 19.1 – id:20151021-061907.
Show that there exists a local maximum for the function $A(x) = -2x^2 + 24x$ at $x = 6$.

S

Solution: We are interested in how the value of the derivative changes about the value $x = 6$. In order to show that $x = 6$, we need to show that the value of the derivative at $x = 6$ is zero, the value of the derivative for $x < 6$ are positive and values of the derivative for $x > 6$ are negative.

Differentiating the function

$$\begin{aligned} A(x) &= \neg 2x^2 + 24x && \text{ONeg(3.1a)} \\ A'(x) &= \neg 4x + 24 && \text{Differentiate goto 17.6} \end{aligned}$$

By solving the equation where the value of the derivative is equal to zero, $\neg 4x + 24 = 0$, for x, we get $x = 6$ goto 13.10.

Using the first derivative test table to organizer the testing of our values of the derivative.

1st Derivative Test Table

x	$x < 6$	$x = 6$	$x > 6$
$f'(x)$	$+$	0	$-$
$f(x)$	$\nearrow$	$\longrightarrow$	$\searrow$
C.P.		Max	

D

Dependencies:example 23.1-20151020-171605

Example 19.2 – 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:

$$
\begin{aligned}
f(x) &= 2x^3 + \neg 3x^2 + \neg 12x + 1 && \text{DOS(4.12a)}\\
[f(x)]' &= [2x^2 + \neg 3x^2 + \neg 12x + 1]' && \text{SPE(4.15)}\\
f'(x) &= [2x^3]' + [\neg 3x^2]' + [\neg 12x]' + [1]' && \text{DS(7.7)}\\
f'(x) &= 2[x^3]' + \neg 3[x^2]' + \neg 12[x]' + [1]' && \text{DCM(7.3)}\\
f'(x) &= 2(3x^2) + \neg 3(2x) + \neg 12(1) + [1]' && \text{DPo(7.5)}\\
f'(x) &= 6x^2 + \neg 6x + \neg 12 + [1]' && \text{OOM(2.4)}\\
f'(x) &= 6x^2 + \neg 6x + \neg 12 + 0 && \text{DC(7.1)}\\
f'(x) &= 6x^2 + \neg 6x + \neg 12 && \text{AId(4.4a)}
\end{aligned}
$$

Solving the equation $6x^2 + \neg 6x + \neg 12 = 0$ to find the x value(s) of the critical points, goto 14.2, 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.

$$
\begin{aligned}
f(2) &= -19 \ \text{goto } 15.1\\
f(-1) &= 8 \ \text{goto } 15.2
\end{aligned}
$$

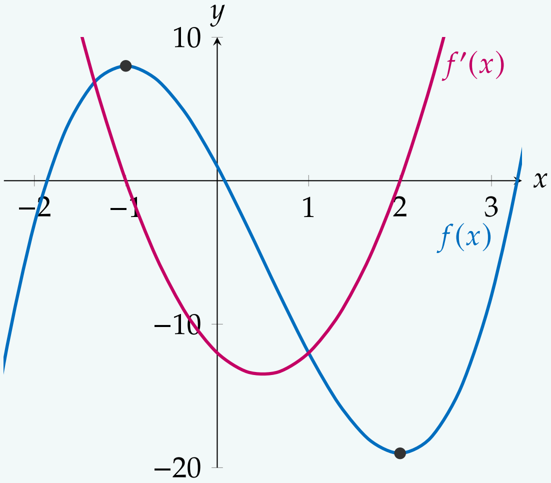
Therefore the critical points are $(2, -19)$ and $(-1, 8)$.

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 used 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	$+$
$f(x)$	$\nearrow$	$\longrightarrow$	$\searrow$	$\longrightarrow$	$\nearrow$
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.



y
10
−10
−20
x
−2
−1
1
2
3
f′(x)
f(x)

20. Local Extrema

20.0.1 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 20.1 – 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 $f(x)$

$$
\begin{aligned}
[f(x)]' &= [ax^2 + bx + c]' && \text{SPE(4.15)}\\
f'(x) &= [ax^2]' + [bx]' + [c]' && \text{DS(7.7)}\\
f'(x) &= a\,[x^2]' + b\,[x]' + [c]' && \text{DCM(7.3)}\\
f'(x) &= 2\cdot a\cdot x + b\cdot 1 + [c]' && \text{DPo(7.5)}\\
f'(x) &= 2\cdot a\cdot x + 1\cdot b + [c]' && \text{CPM(4.6)}\\
f'(x) &= 2ax + 1b + [c]' && \text{CTJ(3.6)}\\
f'(x) &= 2ax + b + [c]' && \text{MId(4.9b)}\\
f'(x) &= 2ax + b + 0 && \text{DC(7.1)}\\
f'(x) &= 2ax + b && \text{AId(4.4b)}
\end{aligned}
$$

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

$$
\begin{aligned}
f'(x) &= 0\\
2ax + b &= 0\\
x &= -\frac{b}{2a} \quad \text{goto } 13.11
\end{aligned}
$$

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 20.2 – id:20150923-152515.
Find the vertex of the parabola $y = x^2 - 2x - 6$ using differentiation.

S

1. Differentiate the function.

$$\begin{aligned}
f(x) &= x^2 - 2x - 6 && \\
f(x) &= x^2 + \neg 2x + \neg 6 && \text{DOS(4.12a)} \\
\left[f(x)\right]' &= \left[x^2 + \neg 2x + \neg 6\right]' && \text{SPE(4.15)} \\
f'(x) &= \left[x^2\right]' + \left[\neg 2x\right]' + \left[\neg 6\right]' && \text{DS(7.7)} \\
f'(x) &= \left[x^2\right]' + \neg 2\left[x\right]' + \left[\neg 6\right]' && \text{DCM(7.3)} \\
f'(x) &= 2x + \neg 2 + \left[\neg 6\right]' && \text{DPo(7.5)} \\
f'(x) &= 2x + \neg 2 + 0 && \text{DC(7.1)} \\
f'(x) &= 2x + \neg 2 && \text{AId(4.4b)} \\
f'(x) &= 2x - 2 && \text{DOS(4.12b)}
\end{aligned}$$

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

$$\begin{aligned}
2x - 2 &= 0 \\
x &= 1
\end{aligned}$$

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

$$\begin{aligned}
f(x) &= x^2 - 2x - 6 && \\
f(1) &= [1]^2 - 2[1] - 6 && \text{SPE(4.15)} \\
f(1) &= -7 && \text{Evaluate}
\end{aligned}$$

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

21. Second Derivative Test

Example 21.1 – id:20151021-063855.
Show that there exists a local maximum for the function $A(x) = -2x^2 + 24x$ at the critical point $x = 6$.

S

Solution: We need to find the second derivative of the function $A(x)$, so we will first find the derivative.

$$\begin{aligned} A(x) &= \neg 2x^2 + 24x && \text{ONeg(3.1a)} \\ A'(x) &= \neg 4x + 24 && \text{Differentiate goto 17.6} \end{aligned}$$

Finding the second derivative

$$\begin{aligned} A'(x) &= \neg 4x + 24 \\ [A'(x)]' &= [\neg 4x + 24]' && \text{SPE(4.15)} \\ A''(x) &= [\neg 4x]' + [24]' && \text{DS(7.7)} \\ A''(x) &= \neg 4\,[x]' + [24]' && \text{DCM(7.3)} \\ A''(x) &= \neg 4(1) + [24]' && \text{DPo(7.5)} \\ A''(x) &= \neg 4 + [24]' && \text{OOM(2.4)} \\ A''(x) &= \neg 4 + 0 && \text{DC(7.1)} \\ A''(x) &= \neg 4 && \text{AId(4.4b)} \\ A''(x) &= -4 && \text{ONeg(3.1b)} \end{aligned}$$

Since the value of the second derivative is a constant and negative, we then know that the function $A(x)$ is always concave down and consequently the critical point at $x = 6$ must be a maximum.

D

Dependencies: example 23.1-20151020-171605

22. Curve Sketching

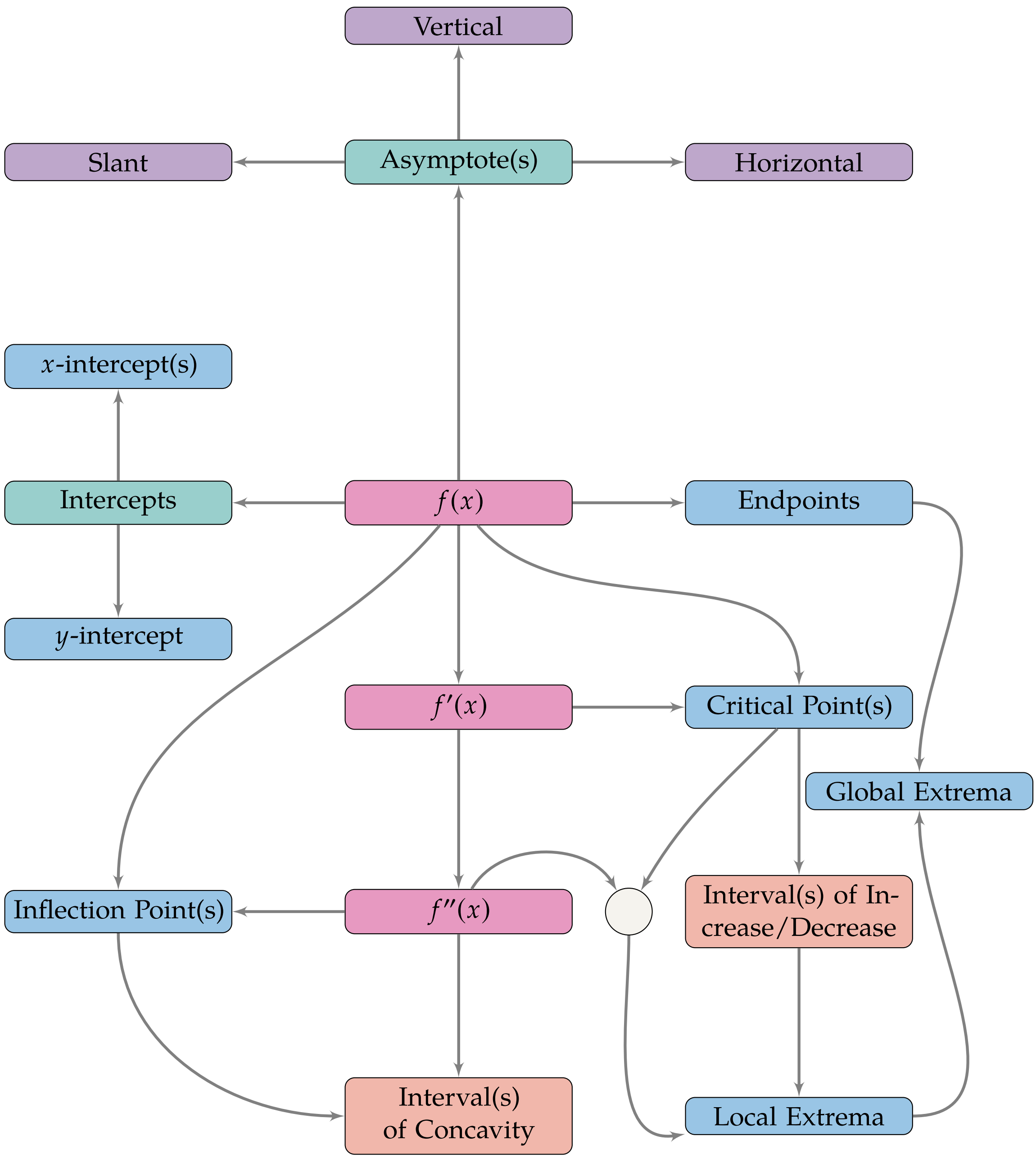


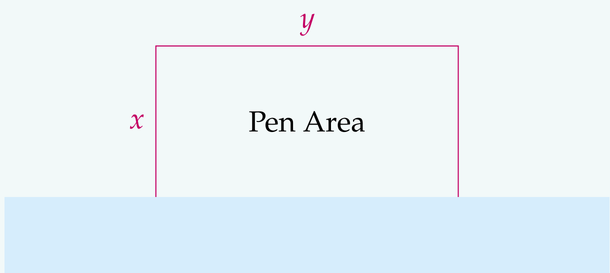
Figure 22.1: Overview of Curve Sketching

23. Optimization Problems

Example 23.1 – id:20151020-171605.
Mark has 24 meters of fencing to build a rectangular pen for his two mini pigs situation along a river. If he is not going to place fencing along the river, then what are the dimensions of the pen that produce the largest area?

S

Solution:
Let x be the width of the pen and y be the length. See the figure below:



We are then able to express the area of the pen in terms of the width x and the length y.

$$\text{Area} = xy$$

The problem is that the area is expressed in terms of two variables x and y. The challenge is now to find a second relationship between these. Since we are given the total length of fencing available, 24m, we can express the perimeter of fencing available in terms of the two variables x and y. Furthermore, we can express y in terms of only the variable x.

$$\begin{aligned}
\text{Perimeter of Fencing} &= x + y + x \\
\text{Perimeter of Fencing} &= 2x + y && \text{Simplify goto 11.3} \\
24\,\text{m} &= 2x + y && \text{SPE(4.15)} \\
y &= -2x + 24\,\text{m} && \text{Solve for } y \text{ goto 13.9}
\end{aligned}$$

$$\begin{aligned} A &= xy \\ A &= x\left[\mathbf{-2x + 24x\,m}\right] && \text{SPE(4.15)} \\ A &= -2x^2 + 24x\,\mathrm{m} && \text{Simplify goto 10.36} \end{aligned}$$

We are now interested in finding the maximum of the graph of the function $A(x) = -2x^2 + 24$. We can do this by finding if a critical point exists and subsequently showing that it can be classified as a maximum point.

$$\begin{aligned} [A(x)]' &= \left[\mathbf{-2x^2 + 24x\,m}\right] && \text{SPE(4.15)} \\ A'(x) &= -4x + 24\,\mathrm{m} && \text{Differentiating goto 18.1} \end{aligned}$$

Find the x value of the critical point by setting the derivative equal to zero and solving for x.

$$\begin{aligned} -4x + 24\,\mathrm{m} &= 0 \\ x &= 6\,\mathrm{m} && \text{Solving goto 13.10} \end{aligned}$$

There is one critical point at $x = 6\,\mathrm{m}$. We now need to show that it is a local maximum value. We can do this using the second derivative test (goto 21.1) or the first derivative test (goto 19.1).

Now that we have shown that the area function $A(x)$ has a maximum value at the critical point $x = 6\,\mathrm{m}$, we know that the width, x, will be 6 m when the area has reached a maximum value. We can find the length, y, of the pen by using the perimeter equation that we used earlier.

$$\begin{aligned} y &= -2x + 24\,\mathrm{m} \\ y &= -2\left[\mathbf{6\,m}\right] + 24\,\mathrm{m} && \text{SPE(4.15)} \\ y &= -12\,\mathrm{m} + 24\,\mathrm{m} && \text{OOM(2.4)} \\ y &= 12\,\mathrm{m} && \text{OOA(2.1)} \end{aligned}$$

It might also be worth finding the maximum area of the pen.

$$\begin{aligned} A &= xy \\ A &= \left[\mathbf{6\,m}\right]\left[\mathbf{12\,m}\right] && \text{SPE(4.15)} \\ A &= 72\,\mathrm{m}^2 && \text{Simplify goto 10.18} \end{aligned}$$

■

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Books

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