Intermediate value theorem worksheet with answers pdf

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Theorem 2
Intermediate Value Theorem for Derivatives

If a and b are any two points on an interval on which f is differentiable, then f' takes on <u>every value</u> between f'(a) and f'(b).

Example 5 When considering Theorem 2, does any function have the unit step function as its derivative?

U(x) = -1, x < 0 Graph looks like:
1, x ≥ 0

First, claim $f(0) = 0$. We have $f(f(0)) = k0^9 = 0$, so

$$f(0) = f(f(f(0))) = k(f(0))^9.$$

Then $f(0) = 0$ or $1 = k(f(0))^8$, but the latter is impossible for negative k, so $f(0) = 0$.

Next, we produce a $c \neq 0$ with $f(c) = 0$. Consider $f(1)$, which may be zero, positive, or negative.

- If $f(1) = 0$, let $c = 1$.
- If $f(1) > 0$, then let $a = 1$ and $b = f(1)$. Then $f(a) = f(1) > 0$ and $f(b) = f(f(1)) = k < 0$, so by the IVT there is a c between a and b with $f(c) = 0$. $c \neq 0$ since a and b are both positive.
- If $f(1) < 0$, then let $a = f(1) < 0$ and $b = f(f(1)) = k < 0$. Then $f(a) = f(f(1)) = k < 0$, and $f(b) = f(f(a)) = ka^9 > 0$, so by the IVT, there is c between a and b with $f(c) = 0$. $c \neq 0$ since a and b are both negative.

Finally, we have a contradiction, since $kc^9 = f(f(c)) = f(0) = 0$ implies $c = 0$. This shows f cannot exist for $k < 0$. □

10. Let $f(x)$ be differentiable on $[0, 1]$ with $f(0) = 0$ and $f(1) = 1$. For each positive integer n, show that there exist distinct points $x_1, x_2, \ldots, x_n$ in $[0, 1]$ such that

$$\sum_{i=1}^{n} \frac{1}{f'(x_i)} = n.$$

11. (MCMC 2004 II.1) Suppose f is a continuous real-valued function on the interval $[0, 1]$. Show that

$$\int_0^1 x^2 f(x)\,dx = \frac{1}{3} f(\xi)$$

for some $\xi \in [0, 1]$.

Solution. Because f is continuous, it attains its minimum and maximum at points a and b, both in $[0, 1]$, giving

$$f(a)\int_0^1 x^2 dx \le \int_0^1 x^2 f(x)\,dx \le f(b)\int_0^1 x^2\,dx$$

or

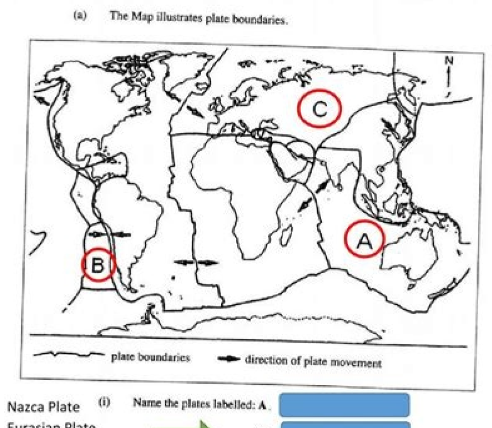
$$f(a) \le 3\int_0^1 x^2 f(x)\,dx \le f(b).$$

Thus, the Intermediate Value Theorem guarantees a point $\xi \in [0, 1]$ such that

$$f(\xi) = 3\int_0^1 x^2 f(x)\,dx.$$

Name: ______________ Grade: ________ Date: ________

(a) The Map illustrates plate boundaries.



Nazca Plate
Eurasian Plate
Indo- Australian Plate
Caribbean Plate

(i) Name the plates labelled: A. B. C. [3]

(ii) List **THREE** types of plate boundary.

Transform Plate Boundary
Convergent Plate Boundary
Divergent Plate Boundary
Tectonic Plate Boundary
Mid- Atlantic Boundary
Sea Floor Spreading

[2]

Energy Transformation Game

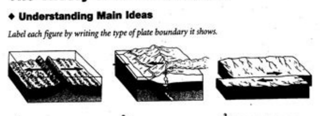
Sun	Windmill	Microwave	Solar Calculator	Crane	Satellite Dish	Siren
Tanning Bed	Nuclear Power Plant	Hot-air Balloon	Magnifying Glass	Candle	Electric Guitar	Firecracker
Battery	Piano	Light Bulb	Mixer	Iron	Lightstick	Bicycle
Television	Person Eating	Plant				

Em = Electromagnetic E = Electrical Mp = Mechanical (potential)
T = Thermal C = Chemical Mk = Mechanical (kinetic
N = Nuclear

SECTION 4-3 REVIEW AND REINFORCE

The Theory of Plate Tectonics

Understanding Main Ideas



Building Vocabulary

How to use intermediate value theorem.

paperDownloadPDF Pack LectureSectionTopicsIntroduction and Basic Principles of ModelingDiscrete Dynamical SystemsDiscrete Stochastic ModelsStages, States, and ClassesContinuous Dynamical SystemsContinuous Dynamical Systems (continued) and Related TopicsContinuous Stochastic ModelsMathematical Contest in Modeling: Student Discussions and Projects Math 61: Introduction to Discrete Structures Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 31A, 31B. Not open for credit to students with credit for courses 180 or 184. Discrete structures commonly used in computer science and mathematics, including sets and relations, permutations and combinations, graphs and trees, induction. P/NP or letter grading. The following schedule, with textbook sections and topics, is based on 26 lectures. The remaining three classroom meetings are for two midterm exams and a review. These are scheduled by the individual instructor. Often there are midterm exams about the beginning of the fourth and eighth weeks of instruction.R. Johnsonbaugh, Discrete Mathematics (8th Edition), Prentice-Hall.LectureSectionTopicsEquivalence relations, matrices of relationsBasic counting principlesPermutations and combinationsGeneralized permutations and combinationsSolving recurrence relations (including material in exercises 40-46)Decision trees, sorting (including merge sort from 7.3) Math 70: Introduction to Probability Course Description(4) Lecture, 3 hours; discussion, 1 hour. Requisites: courses 31A, 31B. Introduction to probability through applications and examples. Topics include laws of large numbers, statistics, chance trees, conditional probability, Bayes? rule, continuous and discrete random variables, jointly distributed random variables, multivariate normal and conditional distributions. In depth discussion of betting schemes in gambling, occurrence of rare events, coincidences and statistical precisions. P/NP or letter grading.The course introduces a list of standard probabilistic problems and analyzes them in detail within the formalism of probability as a mathematical discipline. At the end of the course, the students will be able to demonstrate their understanding of the foundations and basic facts of probability as a mathematical discipline and apply them to resolve questions with probabilistic content.Tijms, H. Understanding Probability, Chance Rules in Everyday Life, 3rd Edition. Cambridge University Press, 2012LectureSectionTopicsLaws of large numbers and simulationsProbability and countingConditional probabilityProbability and expected valueProbability in everyday life and eventsProbability and Bayes? RuleDiscrete random variables and their densitiesContinuous random variablesJointly distributed random variablesMultivariate normal distributionConditional random variablesDistributions Math 73XP: Key Issues in K-12 Mathematics Course Description(3) Seminar, two hours; fieldwork (classroom observation and participation), two hours. Introduces students to K-12 mathematics activity in the United States. Cultivate interest in teaching through exploration of the sequences of mathematical content and habits of mind taught in these grades. Analyze sequences of topics in the current California State Standards in Mathematics (CCSS-M), the mathematical structures that underlie these sequences and cognitive aspects of learning mathematics. Experience with professional mathematician?s habits of mind outlined in the California Standards for Mathematical Practice (including proof and mathematical modeling) and effective strategies for teaching mathematics to diverse student groups. Fieldwork in local mathematics classrooms arranged by Cal Teach program. P/NP (undergraduates) or S/U (graduates) grading.National Research Council How Students Learn: Mathematics in the Classroom. Washington, DC: The National Academies Press, 2005.Other reading materials to be provided online Resources:National Governors Association & Council of Chief State School Officers Common Core State Standards for Mathematics, 2010.LectureSectionTopicsGrades 1-3: Length (CCSS-M 1.MD.2, 2.MD.3, 3.MD.4)Grades 3-5: Area & Volume Defined (CCSS-M 3.MD.5 - 7, 5.MD.3 - 5)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 1 in the classroom?Grades K-6: Deriving Area and Volume Formulas (CCSS-M 6.G., 7.G.4, 8.G.9)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 2 in the classroom?Grades 3-5: Areas and Volumes of Irregular Shapes and Solids (CCSS-M 6.G.1)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 3 in the classroom?Grades K-2: Decomposing Shapes (CCSS-M K.G.6, 1.G.2, 2.G.3)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 4 in the classroom?Grades 3-5: Defining Fraction as a Number (CCSS-M 3.NF.1, 3.NF.2)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 5 in the classroom?Student Presentation of Performance TasksFieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 6 in the classroom?Grades 3-5: Multiplying Fractions (CCSS-M 5.NF.4)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 7 in the classroom?Grades 6-7: Ratios and Proportional Relationships (CCSS-M 6.RP.3, 7.RP.2)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 8 in the classroom?Grades K-12: Linear and Other Functions (CCSS-M 8.EE.6, 8.F.1, 8.F.2, HSF.IF.1) Math 74XP: Mathematics and Pedagogy for Teaching Elementary Mathematics Course Description(3) Seminar, two hours; fieldwork (classroom observation and participation), two hours. Facilitate development of professional mathematical and pedagogical understandings required to teach California?s K-5 mathematics curriculum. Exploration of K-5 mathematics, practice effective teaching strategies for all learners, and discuss current research and standards in math education. Fieldwork in local mathematics classrooms (observation and presenting lesson plan) arranged by Cal Teach program. P/NP (undergraduates) or S/U (graduates) grading.Berlinghoff & Gouvea Math Through The Ages: A Gentle History for Teachers and Others. Oxton Publishers & MAA, 2015.Other reading materials to be provided.LectureSectionTopicsGrades K-2: Connecting Counting to Cardinality (CCSS-M K.CC.4)Grades K-2: The Base Ten System (CCSS-M 1.NBT.2, 2.NBT.1)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 1 in the classroom?Grades K-2: The Addition & Subtraction Algorithms (CCSS-M 2.NBT.9, 3.NBT.2)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 2 in the classroom?Grades 3-5: Adding and Subtracting Fractions (CCSS-M 4.NF.3)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 3 in the classroom?Grades 3-5: Relating Area to Multiplication (CCSS-M 3.MD.7)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 4 in the classroom?Grades 3-5: The Multiplication Algorithm for Whole Numbers (CCSS-M 4.NBT.5, 5.NBT.5)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 5 in the classroom?Grades 3-5: Student Presentations of Lesson PlansFieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 6 in the classroom?Grades 3-5: Multiplying Fractions (CCSS-M 5.NF.4)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 7 in the classroom?Grades 3-5: Dividing Fractions (CCSS-M 5.NF.7)Fieldwork Prompt: In what ways (if any) did you observe students engaging in CCSS SMP 8 in the classroom?Grades 3-5: Decimals & Decimal Operations (CCSS-M 4.NF.5-7, 5.NBT.7, 6.NS.3) Math 89HC: Honors Contracts Course Description(1) Tutorial, three hours. Limited to students in College Honors Program. Designed as adjunct to lower-division lecture course. Individual study with lecture course instructor to explore topics in greater depth through supplemental readings, papers, or other activities. May be repeated for maximum of 4 units. Individual honors contract required. Honors content noted on transcript. Letter grading. Math 100: Problem Solving Course Description(4) (Formerly numbered 192.) Lecture, three hours. Requisite: course 31B with grade of C- or better. Problem-solving techniques and mathematical topics useful as preparation for Putnam Examination and similar competitions. Continued fractions, inequalities, modular arithmetic, closed form evaluation of sums and products, problems in geometry, rational functions and polynomials, other nonroutine problems. Participants expected to take Putnam Examination. P/NP grading.Problem-Solving Through Problems by Loren C. LarsonLectureSectionTopicsInduction. Generalized induction. The pigeonhole principle.Inequalities (AM-GM, weighted AM-GM, Cauchy-Schwartz, Jensen, Holder, Minkowski).Number theory. Modular arithmetic. Fermat’s little theorem, Euler’s theorem. The Chinese remainder theorem.Algebra. Polynomials (factorization over different fields, Viete’s relations). Some abstract algebra (groups, rings).Summation of series. Geometric progressions. Telescoping series and products. Taylor series.Combinatorics. Binomial coefficients and combinatorial identities.Recurent sequences (linear recurrences, generating functions). Discrete and continuous probability.Geometry problems. Elementary methods. Analytic geometry, conics. Vectors and complex numbers.Differential calculus. The extreme value theorem and the mean value theorem. Functional equations.Integral calculus. Approximating integrals by Riemann sums. Integral functional equations. Math 101: Advanced Problem Solving Course Description(4) Lecture, three hours. Prerequisite: Math 100 or significant experience with mathematical competitions. Advanced problem solving techniques and mathematical topics useful as preparation for Putnam Competition. Problems in abstract algebra, linear algebra, number theory, combinatorics, probability, real and complex analysis, differential equations, Fourier analysis. Regular practice tests given, similar in difficulty to the Putnam Competition. Enrollment is by permission of the instructor, based on a selection test or past Putnam results. May be repeated for maximum of 12 units. P/NP or letter grading.R. Gelca & T. Andreescu. Putnam and Beynd, Springer VerlagLectureSectionTopicsIntroduction to the Putnam Mathematical Competition. Selected test problems from previous years.Methods of proof: contradiction, induction, the pigeonhole principle, invariants.Algebra. Inequalities and identities. Real and complex polynomials.Linear Algebra. Eigenvalues, the Cayley-Hamilton Theorem. Abstract algebra (groups, rings).Geometry and trigonometry. Using vectors and complex numbers to solve gemetry problems.Number theory. Euler’s theorem. Diophantine equations.Combinatorics and combinatorial geometry. Generating functions. Probability.Real analysis problems. Sequences, series, continuity, derivatives and integrals. Convexity.Multivariable differential and integral calculus. Solving integrals using complex analysis.Differential equations and Fourier analysis. Math 103A: Observation and Participation: Mathematics Instruction Course Description(2) (Formerly Math 330.) Seminar, one hour; fieldwork (classroom observation and participation), two hours. Requisites: courses 31A, 31B, 32A, 33A, 33B. Course 103A is enforced requisite to 103B, which is enforced requisite to 103C. Observation, participation, or tutoring in mathematics classes at middle school and secondary levels. May be repeated for credit. P/NP (undergraduates) or S/U (graduates) grading. Math 103B: Observation and Participation: Mathematics Instruction Course Description(2) (Formerly Math 330.) Seminar, one hour; fieldwork (classroom observation and participation), two hours. Requisites: courses 31A, 31B, 32A, 33A, 33B. Course 103A is enforced requisite to 103B, which is enforced requisite to 103C. Observation, participation, or tutoring in mathematics classes at middle school and secondary levels. May be repeated for credit. P/NP (undergraduates) or S/U (graduates) grading. Math 103C: Observation and Participation: Mathematics Instruction Course Description(2) (Formerly Math 330.) Seminar, one hour; fieldwork (classroom observation and participation), two hours. Requisites: courses 31A, 31B, 32A, 32B, 33A, 33B. Course 103A is an enforced requisite to 103B, which is enforced requisite to 103C. Observation, participation, or tutoring in mathematics classes at middle school and secondary levels. May be repeated for credit. P/NP (undergraduates) or S/U (graduates) grading. Math 105A: Mathematics and Pedagogy for Teaching Secondary Mathematics Course Description(4) Lecture, four hours; fieldwork, 30 minutes. Requisites: courses 110A (or 117), 120A (or 123), and 131A, with grades of C- or better. Course 105A is requisite to 105B, which is requisite to 105C. Mathematical knowledge and research-based pedagogy needed for teaching key geometry topics in secondary school, including axiomatic systems, measure, and geometric transformations. Introduction to professional standards and current research for teaching secondary school mathematics. Letter grading.LectureSectionTopicsIntro to Problem Analysis; intro to definitionNumber: integers ? history and algebraic structure; comparing methods for teaching -(-a)(-b) = +abNumber: rationals ? definition and algebraic structure; comparing models for rational divisionNumber: reals ? decimals, irrationals, countability; method for teaching rational operationsAttendance at all day Texas Instruments PTENumber: complex ? polar, rectangular, and exponential representations and their advantages, De Moivre?s Theorem; model lesson to introduce iNumber: complex ? stereographic projection; model lesson on modeling probabilistic data with linear functionsFunction: definitions; model lesson on modeling probabilistic data with exponential functionsJoint Meeting with the science team: modeling one dimensional motion with linear and quadratic functionsFunction: model lesson on maximum box volume problem; review for final Math 105B: Mathematics and Pedagogy for Teaching Secondary Mathematics Course Description(4) Lecture, four hours; fieldwork, 30 minutes. Requisites: courses 105A, 110A (or 117), 120A (or 123), and 131A, with grades of C- or better. Mathematical knowledge and research-based pedagogy needed for teaching key polynomial, rational, and transcendental functions and related equations in secondary school; professional standards and current research for teaching secondary school mathematics. Letter grading.LectureSectionTopicsFunction: rational functions; def. of asymptotes; formative assessment in the classroomEquation: preservation of solution sets; comparing strategies for teaching solving linear equationsEquation: preservation of solution sets; comparing strategies for teaching binomial multiplicationEquation: comparing methods for teaching factoring; the quadratic formula; solving the cubicAxiomatic Systems: intro to Euclid; a model secondary lesson on developing the concept of axiomAxiomatic Systems: a model secondary lesson on the triangle sum theorem in spherical geometryAxiomatic Systems: the triangle sum theorem in the hyperbolic geometryMeasure: definition of area; evaluating student work on intro to integral project; model lesson to develop elementary polygon areasAttendance at day long UCLA Mathematics and Teaching ConferenceAttendance at annual UCLA California Math Teacher Program Reunion Dinner Math 105C: Mathematics and Pedagogy for Teaching Secondary Mathematics Course Description(4) Lecture, four hours; fieldwork, 30 minutes. Requisites: courses 105A, 105B, 110A (or 117), 120A (or 123), and 131A, with grades of C- or better. Mathematical knowledge and research-based pedagogy needed for teaching key analysis, probability, and statistics topics in secondary school; professional standards and current research for teaching secondary school mathematics. Letter grading.LectureSectionTopicsMore on Measure: Area: Pythagorean Theorem. Measure: VolumeStudent Presentations of Lesson PlanStudent Presentations of Lesson Plan. Transformations: Symmetries.Transformations: Congruence and Similarity. Transformations: in the Cartesian plane.Trigonometry: Circular functions, similarity. Trigonometry and complex numbers.Probability: finite. Probability: geometric.Student Presentations of videotaped teachingStudent Presentations of math paper Math 106: History of Mathematics Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 31A, 31B, 32A. Roots of modern mathematics in ancient Babylonia and Greece, including place value number systems and proof. Development of algebra through Middle Ages to Fermat and Abel, invention of analytic geometry and calculus. Selected topics. P/NP or letter grading.Stillwell, J., Mathematics and its History, 3rd Ed., Springer. Math 110AH: Algebra (Honors) Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A. Not open for credit to students with credit for course 117. Ring of integers, integral domains, fields, polynomial domains, unique factorization. Honors sequence parallel to courses 110A. P/NP or letter grading.The following schedule anticipates 24 days of instruction, with 2 holidays and 4 days for exams and reviews. If there is extra time, one could do section 6.3 – the structure of R/I when I is prime or maximal and/or section 4.6 – irreducibility in R[x] or C[x].R. Elman, Lectures on Abstract AlgebraBook is Subject to Change Without NoticeLectureSectionTopicsThe Integers: Well ordering and greatest common divisors.Equivalence relations, modular arithmeticGroups: Definitions and exampleFinite abelian groups, SeriesGroup actions: orbit decomposition theorem.Examples of Group actionsSylow theorems. Application of Sylow theoremsSymmetric and Alternating groups Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A. Not open for credit to students with credit for course 117. Ring of integers, integral domains, fields, polynomial domains, unique factorization. P/NP or letter grading.The following schedule anticipates 24 days of instruction, with 2 holidays and 4 days for exams and reviews. If there is extra time, one could do section 6.3 – the structure of R/I when I is prime or maximal and/or section 4.6 – irreducibility in R[x] or C[x].Hungerford, T.,Abstract Algebra, 3rd Ed., Brooks Col.LectureSectionTopicsDivision Algorithm, divisibility, primes, and unique factorization.Congruence and congruence classes, modular arithmetic, Z/pZ when p is a prime.Definition and examples of rings, basic properties.Isomorphisms and homomorphism of rings. Review and first midterm. [Note: The book does isomorphism first then homomorphism. The order should probably be inverted.]Polynomials and the Division Algorithm, divisibility in F[x], irreducibles, and unique factorization.Polynomial functions, roots, and reducibility, irreducibility in Q[x].Review, second midterm. Congruence in F[x] and congruence classes.Congruence class arithmetic, the structure of F[x]/(p(x)) when p(x) is irreducible.Ideals and congruence, quotient rings and homomorphisms. Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 110A or 117. Groups, structure of finite groups. P/NP or letter grading.The course should cover essentially the material between pages 160 and 280 (excluding the section on the simplicity of the appropriate alternating groups; one can come back to this if there is enough time). If there is not enough time, the material at the beginning is more important than the material at the end.Hungerford, T., Abstract Algebra, 3rd Ed., Brooks Col.LectureSectionTopicsDefinition of groups, basic properties.Subgroups, isomorphism, and homomorphism.Congruence and Lagrange’s Theorem, normal subgroups.Quotient groups, review, first midterm.Quotient groups and homomorphism, symmetric and alternating groups.Direct products, finite abelian groups.The Sylow Theorems, review, second midterm.Conjugacy and proof of the Sylow Theorems.The structure of finite groups, groups of small order. Math 110BH: Algebra (Honors) Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 110A or 117. Groups, structure of finite groups. P/NP or letter grading.The course should cover essentially the material between pages 160 and 280 (excluding the section on the simplicity of the appropriate alternating groups; one can come back to this if there is enough time). If there is not enough time, the material at the beginning is more important than the material at the end.Dummit and Foote, Abstract Algebra, 3rd Ed., Wiley & Sons.Book is Subject to Change Without NoticeLectureSectionTopicsDefinition of groups, basic properties.Subgroups, isomorphism, and homomorphism.Congruence and Lagrange’s Theorem, normal subgroups.Quotient groups, review, first midterm.Quotient groups and homomorphism, symmetric and alternating groups.Direct products, finite abelian groups.The Sylow Theorems, review, second midterm.Conjugacy and proof of the Sylow Theorems.The structure of finite groups, groups of small order. Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 110A, 110B. Field extensions, Galois theory, applications to geometric constructions, and solvability by radicals. Math 111: Theory of Numbers Course Description(4) Lecture, three hours; discussion, one hour. Requisite: courses 110A. Algebraic number theory (including prime ideal theory), cyclotomic fields and reciprocity laws, Diophantine equations (especially quadratic forms, elliptic curves), equations over finite fields, topics in theory of primes, including prime number theorem and Dirichlet’s theorem. P/NP or letter grading. Math 114C: Computability Theory Course Description(Formerly numbered 114A). Lecture, three hours; discussion, one hour. Requisite: course 110A or 131A or Philosophy 135. Effectively calculable, Turing computable, and recursive functions; Church/Turing thesis. Normal form theorem; universal functions; unsolvability and undecidability results. Recursive and recursively enumerable sets; relative recursiveness, polynomial-time computability. Arithmetical hierarchy. P/NP or letter grading. Math 114L: Mathematical Logic Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 110A or 131A or Philosophy 135. Introduction to mathematical logic, aiming primarily at completeness and incompleteness theorems of Godel. Propositional and predicate logic; syntax and semantics; formal deduction; completeness, compactness, and Lowenheim/Skolem theorems. Formal number theory: nonstandard models; Godel incompleteness theorem. P/NP or letter grading. Math M114S: Introduction to Set Theory Course Description(Formerly numbered M112.) (Same as Philosophy M134.) Lecture, three hours; discussion, one hour. Prerequisite: course 110A or 131A or Philosophy 135. Axiomatic set theory as framework for mathematical concepts; relations and functions, numbers, cardinality, axiom of choice, transfinite numbers. P/NP or letter grading.Moschovakis, Y., Notes on Set Theory, 2nd Ed., Springer. Math 115A: Linear Algebra Course Description(5) Lecture, three hours; discussion, two hours. Requisite: course 33A. Techniques of proof, abstract vector spaces, linear transformations, and matrices; determinants; inner product spaces; eigenvector theory. P/NP or letter grading.S. Friedberg, et al, Linear Algebra, 5th Ed., Pearson.LectureSectionTopicsVector Spaces over a FieldLinear Combinations and Systems of Linear Equations; Linear Dependence and Linear IndependenceLinear Dependence and Linear Independence; Bases and DimensionsLinear Transformations, Null Spaces, and RangesLinear Transformations, Null Spaces, and RangesLinear Transformations, Null Spaces, and Ranges; The Matrix Representation of a Linear TransformationThe Matrix Representation of a Linear TransformationComposition of Linear Transformations and Matrix MultiplicationInvertibility and IsomorphismsInvertibility and Isomorphisms; The Change of Coordinate MatrixThe Change of Coordinate MatrixSummary – Important Facts about DeterminantsEigenvalues and EigenvectorsEigenvalues and EigenvectorsInner Products and NormsInner Products and Norms; The Gram-Schmidt Orthogonalization Process and Orthogonal ComplementsThe Gram-Schmidt Orthogonalization Process and Orthogonal ComplementsThe Adjoint of a Linear OperatorNormal and Self-Adjoint OperatorsNormal and Self-Adjoint Operators Math 115AH: Linear Algebra (Honors) Course Description(5) Lecture, three hours; discussion, two hours. Requisite: course 33A with grade of B or better. Techniques of proof, abstract vector spaces, linear transformations, and matrices; determinants; inner product spaces; eigenvector theory. Honors course parallel to course 115A. P/NP or letter grading.S. Friedberg, et al, Linear Algebra, 5th Ed., Pearson.Book is Subject to Change Without NoticeLectureSectionTopicsVector Spaces over a FieldLinear Combinations and Systems of Linear Equations; Linear Dependence and Linear IndependenceLinear Dependence and Linear Independence; Bases and DimensionsLinear Transformations, Null Spaces, and RangesLinear Transformations, Null Spaces, and RangesLinear Transformations, Null Spaces, and Ranges; The Matrix Representation of a Linear TransformationThe Matrix Representation of a Linear TransformationComposition of Linear Transformations and Matrix MultiplicationInvertibility and IsomorphismsInvertibility and Isomorphisms; The Change of Coordinate MatrixThe Change of Coordinate MatrixSummary – Important Facts about DeterminantsEigenvalues and EigenvectorsEigenvalues and EigenvectorsInner Products and NormsInner Products and Norms; The Gram-Schmidt Orthogonalization Process and Orthogonal ComplementsThe Gram-Schmidt Orthogonalization Process and Orthogonal ComplementsThe Adjoint of a Linear OperatorNormal and Self-Adjoint OperatorsNormal and Self-Adjoint Operators Math 115B: Linear Algebra Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A. Linear transformations, conjugate spaces, duality; theory of a single linear transformation, Jordan normal form; bilinear forms, quadratic forms; Euclidean and unitary spaces, symmetric skew and orthogonal linear transformations, polar decomposition. P/NP or letter grading.S. Friedberg, et al, Linear Algebra, 5th Ed., Pearson.LectureSectionTopicsReview of Math 115A, Chapters I and IIDual Spaces (This section looks short but the concepts are new and thus will take two lectures to do well)Review Sections 5.1 and 5.2 from 115AInvariant Subspaces and the Cayley Hamilton TheoremInvariant Subspaces and the Cayley Hamilton TheoremInvariant Subspaces and the Cayley Hamilton TheoremReview Sections 6.1 – 6.4 including more detail than was done in 115AReview Sections 6.1 – 6.4 including more detail than was done in 115AUnitary and Orthogonal Operators and their matricesUnitary and Orthogonal Operators and their matricesUnitary and Orthogonal Operators and their matricesOrthogonal Projections and the Spectral TheoremOrthogonal Projections and the Spectral TheoremOrthogonal Projections and the Spectral TheoremThe Geometry of Orthogonal OperatorsThe Geometry of Orthogonal OperatorsThe Geometry of Orthogonal OperatorsJordan Canonical Form I (This is a long and intricate presentation that takes time; do examples along the way!)The Minimal Polynomial (It might actually be better to do this section right after the Cayley Hamilton Theorem)At the discretion of the teacher. Math 116: Mathematical Cryptology Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A. Not open for credit to students with credit for Program in Computing 130. Introduction to mathematical cryptology using methods of number theory, algebra, probability. Topics include symmetric and public-key cryptosystems, one-way functions, signatures, key exchange, groups, primes, pseudoprimes, primality tests, quadratic reciprocity, factoring, rho method, RSA, discrete logs. P/NP or letter grading.The course is planned for 28 lectures, 1 midterm exam, and 1 holiday.Trappe, Intro to Cryptography with Coding Theory, Prentice Hall.LectureSectionTopicsCongruences, Classic Symmetric Ciphers, Intro to Probability. Read: Introduction, 1.1-1.4, 2.1-2.2.Probability (cont.), Applications to Attacks, Permutations. Read: 2.3-2.4, 4.4, 3.1-3.5.4.1-4.2, 6.1-6.3, 7.1-7.2Symmetric Ciphers (Vigenere, DES, AES), Theory of Integers (Factorization, GCD, Euclidean Algorithm). Read: 4.1-4.2, 6.1-6.3, handout on AES (Rijndael), 7.1-7.2.Theory of Integers (Euclidean Algorithm, Equivalence Relations, Integers mod n, Discrete logs, Primitive roots, Linear Algebra mod n), affine cipher. Read: 7.3-7.8, 8.1-8.2.Public Key Ciphers (RSA, Diffie-Hellman, ElGameal, Knapsack). Read 10.1-10.5.Midterm Monday. Roots mod p. Read: 12.1-12.5.13.1-13.3, 13.5-13.7, 15.1-15.5Roots mod n, Quadratic Reciprocity. Read: 13.1-13.3, 13.5-13.7, 15.1-15.5.Pseudo-primes and Primality tests, Prime Generation. Read: 16.1-16.6.Factorization Attacks. Read: 24.1-24.3.Discrete logs, Review. Read: 27.1-27.3. Math 117: Algebra for Applications Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A. Not open for credit to students with credit for course 110A. Integers, congruences; fields, applications of finite fields; polynomials; permutations, introduction to groups.The following schedule is based on 26 lectures. The remaining three classroom meetings are for midterm exams and a review.L. Childs, A Concrete Introduction to Higher Algebra, 3rd Ed., Springer-Verlag.LectureSectionTopicsInduction and binomial theoremEuclidean algorithm, Bezout’s identity, unique factorizationCongruences, congruence classes, and error-correcting codesTheorems of Euler and FermatChinese remainder theoremApplication of Chinese remainder theorem to RSA cryptographyPolynomials, unique factorizationComplex numbers, fundamental theorem of algebraCongruences modulo a polynomial and Chinese remainder theoremFast polynomial multiplication, fast Fourier transform Math 118: Mathematical Methods of Data Theory Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 42 and 115A. Introduction to computational methods for data problems with a focus on linear algebra and optimization. Matrix and tensor factorization, PageRank, assorted other topics in matrices, linear programming, unconstrained optimization, constrained optimization, integer optimization, dynamic programming, and stochastic optimization. P/NP or letter grading.Students will learn key processes of optimization and linear algebra which underlies data science. These include linear programming, unconstrained optimization, constrained optimization, integer optimization, dynamic programming, stochastic optimization, integer optimization, dynamic programming, and stochastic optimization.Required:1. Elden, Lrs. Matrix Methods in Data Mining and Pattern Recognition. The Society for Industrial and Applied Mathematics, 2007.2. Chong, E and S. Zak. An Introduction to Optimization, 4th edition. Wiley, 2013.Supplemental:3. Hillier, Frederick S. and Lieberman, Gerald J. Introduction to Operations Research, 9th edition. McGraw-Hill Higher Education, 2009.LectureSectionTopicsReview of linear algebra, least squares, orthogonality; QR decomposition; Singular-value decomposition (SVD)Elden:Data Mining and Pattern Recognition, Vectors and Matrices (1.1)Matrix-Vector Multiplication, Matrix-Matrix Multiplication, Scalar Product and Vector Norms, Matrix Norms, Linear Independence- Bases, The Rank of a Matrix (1.2, 2.1-2.6)Linear Systems and Least Squares, LU Decomposition, Symmetric, Positive Definite Matrices, Perturbation Theory and Condition Number, Rounding Errors in Gaussian Elimination, Banded Matrices, The Least Squares Problem (3.1-3.6)Orthogonal Vectors and Matrices., Elementary Orthogonal Matrices, Number of Floating Point Operations, Orthogonal Transformations in Floating Point Arithmetic (4.1-4.4)Orthogonal Transformation to Triangular Form, Solving the Least Squares Problem, Computing or Not Computing Q, Flop Count for QR Factorization, Error in the Solution of the Least Squares Problem, Updating the Solution of a Least Squares Problem (5.1-5.2)Singular Value Decomposition, Fundamental Subspaces, Matrix Approximation, Principal Component Analysis, Solving Least Squares Problems, Condition Number and Perturbation Theory for the Least Squares Problem, Rank-Deficient and Under-Determined Systems, Computing the SVD, Complete Orthogonal Decomposition (6.1-6.9)Chong & Zak:Real Vector Spaces, Rank of a Matrix, Linear Equations, Inner Products and Norms (2.1-2.4)Linear Transformation, Eigenvalues and Eigenvectors, Orthogonal Projections, Quadratic Forms, Matrix Norms (3.1-3.5)Reduced-rank least squares; Tensor decomposition; Nonnegative matrix factorizationElden:Truncated SVD: Principal Components Regression, Krylov Subspace Method (7.1-7.2)Introduction to Tensor Decomposition, Basic Tensor Concepts, A Tensor Singular Value Decomposition, Approximating a Tensor by HOSVD (8.1-8.4)Data analysis applications; PagerankElden:The k-Means Algorithm, Non-Negative Matrix Factorization (9.1-9.2)Handwritten Digits and a Simple Algorithm, Classification using SVD Bases, Tangent Distance (10.0-10.3)Preprocessing the Documents and Queries, The Vector Space Model, Latent Semantic Indexing, Clustering, Non-Negative Matrix Factorization, Lanczos-Golub-Kahan Bidiagonalization, Average Performance (11.1-11.7)Pagerank, Random Walk and Markov Chains, The Power Method for Pagerank Computation, HITS (12.0-12.4)Linear optimization: modeling; Standard form; DualityChong & Zak:Introduction to Linear Programing, Simple Examples of Linear Programs, Two-Dimensional Linear Programs, Convex Polyhedra and Linear Programming, Standard Form Linear Programs, Basic Solutions, Properties of Basic Solutions, Geometric View of Linear Programs (15.1-15.8)Solving Linear Equations Using Row Operations, The Canonical Augmented Matrix, Updating the Augmented Matrix, The Simplex Algorithm, Matrix Form of the Simplex Method, Two-Phase Simplex Method, Revised Simplex Method (16.1-16.7)Dual Linear Programs, Properties of Dual Problems (17.1-17.2)Linear optimization solvers (Simplex Method, Interior-Point Method)Chong & Zak:Introduction to Nonsimplex Methods, Khachiyan?s Method, Affine Scaling Method, Karmarkar?s Method (18.1-18.4)Introduction to Problems with Equality Constraints, Problem Formulation, Tangent and Normal Spaces, Lagrange Condition, Second-Order Conditions, Minimizing Quadratics Subject to Linear Constraints (20.1-20.6)Unconstrained optimization: optimality condition, local-vs. global minimum, convex set and function; Solvers such as gradient descent and Newton MethodChong & Zak:Introduction to Convex Optimization Problems, Convex Functions, Convex Optimization Problems (22.1-22.3)Constrained optimization: KKT condition; Solvers such as Gradient Projection Method, Penalty Method and Multipliers MethodChong & Zak:Karush-Kuhn-Tucker Condition, Second-Order Conditions (21.1-21.2)Introduction to Algorithms for Constrained Optimization, Projections, Projected Gradient Methods, Penalty Methods (23.1-23.3, 23.5)Integer optimization: modeling, relaxations; Solvers such as cutting plane, Branch-N-Bound/Cut MethodsHillier & Lieberman:Perspectives on Solving Integer Programming Problems (12.1-12.5)The Branch-and-Bound Technique and Its Application to Binary Integer Programming (12.6)Branch-and-Bound Algorithm for Mixed Integer Programming (12.7)Dynamic programmingHillier & Lieberman:A Prototype Example for Dynamic Programming (11. 1)Characteristics of Dynamic Programming Problems (11.2)Deterministic Dynamic Programming (11.3)Neural networksChong & Zak:Introduction (13.1)Single Neuron Training (13.2) (needs 12.3 – aolution to Ax=b minimizing |x| and 12.4 Kaczmarz?s Algorithm)Backpropagation Algorithm (13.3) Math 120A: Differential Geometry Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B, 115A, 131A. Course 120A is requisite to 120B. Curves in 3-space, Frenet formulas, surfaces in 3-space, normal curvature, Gaussian curvature, congruence of curves and surfaces, intrinsic geometry of surfaces, isometries, geodesics, Gauss/Bonnet theorem. P/NP or letter grading.Millman & Parker, Elements of Differential Geometry, Prentice HallBook is Subject to Change Without NoticeLectureSectionTopics Math 120B: Differential Geometry Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B, 115A, 120A, 131A. Curves in 3-space, Frenet formulas, surfaces in 3-space, normal curvature, Gaussian curvature, congruence of curves and surfaces, intrinsic geometry of surfaces, isometries, geodesics, Gauss/Bonnet theorem. P/NP or letter grading.Millman & Parker, Elements of Differential Geometry, Prentice HallBook is Subject to Change Without NoticeLectureSectionTopics Math 121: Introduction to Topology Course Description(4) Requisite: course 131A. Metric and topological spaces, completeness, compactness, connectedness, functions, continuity, homeomorphisms, topological properties.The following sample schedule, with textbook sections and topics, is based on 25 lectures. Assigned homework problems play an important role in the course, and there is usually a midterm exam.T. Gamelin and R. Greene, Introduction to Topology, 2nd Ed., Dover.LectureSectionTopicsMetric spaces, open and closed sets; completeness, Baire category theorem; euclidean spaceCompactness, characterization of compact metric spacesNormed linear spaces; linear operators, principle of uniform boundedness; contraction mapping principleTopological spaces, subspacesTransfinite induction; infinite product spaces, Tychonoff’s theoremHomotopic paths, fundamental groupCovering spaces; index of circle maps; applications of the index Math 123: Foundations of Geometry Course DescriptionLecture, three hours; discussion, one hour. Prerequisite: course 115A. Axioms and models, Euclidean geometry, Hilbert axioms, neutral (absolute) geometry, hyperbolic geometry, Poincare model, independence of parallel postulate.The purpose of Math 123 is to study the classical geometries from an axiomatic perspective, with particular attention paid to Euclid’s parallel postulate and to geometric systems that violate it. These systems are called Non-Euclidean Geometries. Among them, the Hyperbolic Geometry is the most important today. Here is some background. Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B. Recommended: course 115A. Rigorous introduction to foundations of real analysis; real numbers, point set topology in Euclidean space, functions, continuity.The following schedule, with textbook sections and topics, is based on 26 lectures. The remaining three classroom meetings are for leeway, reviews, and midterm exams. These are scheduled by the individual instructor. Often there are midterm exams about the beginning of the fourth and eighth weeks of instruction, plus reviews for the final exam.K.A. Ross, Elementary Analysis: The Theory of Calculus, 2nd Ed.LectureSectionTopicsInduction and Rational Numbers.Real Numbers, Least Upper Bound AxiomLimits of Sequences, Limit Theorems.Monotone Sequences, Cauchy Sequences, Midterm I.Subsequences, Bolzano-Weierstrass, Limsup and Liminf.Convergence Tests, Continuous Functions.Limit Theorems, Uniform Continuity.Derivative, Mean Value Theorem, Midterm II.Taylor’s Theorem, Riemann Integral, Properties of Riemann Integral.Fundamental Theorem of Calculus, Review of Course. Math 131AH: Analysis (Honors) Course Description(4) Lecture, three hours; discussion, one hour. Requisites for course 131AH: courses 32B and 33B, with grades of B or better. Recommended: course 115A. Honors sequence parallel to courses 131A. P/NP or letter grading. Rigorous introduction to foundations of real analysis; real numbers, point set topology in Euclidean space, functions, continuity.The following schedule, with textbook sections and topics, is based on 26 lectures. The remaining three classroom meetings are for leeway, reviews, and midterm exams. These are scheduled by the individual instructor. Often there are midterm exams about the beginning of the fourth and eighth weeks of instruction, plus reviews for the final exam.Rudin, W., Principles of Mathematical Analysis, 3rd Ed, McGraw-Hill Higher EducationCopson, E. Metric Spaces, Cambridge University PressLectureSectionTopicsInduction and Rational Numbers.Real Numbers, Least Upper Bound AxiomLimits of Sequences, Limit Theorems.Monotone Sequences, Cauchy Sequences, Midterm I.Subsequences, Bolzano-Weierstrass, Limsup and Liminf.Convergence Tests, Continuous Functions.Limit Theorems, Uniform Continuity.Derivative, Mean Value Theorem, Midterm II.Taylor’s Theorem, Riemann Integral, Properties of Riemann Integral.Fundamental Theorem of Calculus, Review of Course. Math 131BH: Analysis (Honors) Course Description(4) Lecture, three hours; discussion, one hour. P/NP or letter grading. Requisites: courses 33B, 115A, 131A. Derivatives, Riemann integral, sequences and series of functions, power series, Fourier series.The following schedule, with textbook sections and topics, is based on 26 lectures. The remaining classroom meetings are for leeway, reviews, and midterm exams. These are scheduled by the individual instructor. Often there are midterm exams about the beginning of fourth and eighth weeks of instruction, plus reviews for the final exam.Rudin, W., Principles of Mathematical Analysis, 3rd EdCopson, E. Metric Spaces, Cambridge University PressLectureSectionTopicsMetric Spaces, Some Point-Set Topology and Relative TopologyCauchy Sequences and Completeness, Compact Metric Spaces, Continuous Functions on Metric SpacesContinuity on Product, Connected and Compact Metric SpacesUniform Convergence, Midterm IUniform Convergence and Continuity, the “Sup” Norm, Series of Functions, Uniform Convergence in Integration and Differentiation3Formal Power Series, Real Analytic Functions, Abel’s Theorem (Optional)4, Multiplication of Power SeriesExponential and Logarithmic Functions, Trigonometric Functions, Periodic FunctionsInner Products on Periodic Functions, Trigonometric Polynomials, Hour Exam IIPeriodic Convolutions, L2 convergence of Fourier Series and Plancherel’s Theorem, Differentiability of Functions of Several VariablesThe Several Variable Chain Rule, Clairaut’s Theorem, Review of Course Course Description(4) Lecture, three hours; discussion, one hour. P/NP or letter grading. Requisites: courses 33B, 115A, 131A. Derivatives, Riemann integral, sequences and series of functions, power series, Fourier series.The following schedule, with textbook sections and topics, is based on 26 lectures. The remaining classroom meetings are for leeway, reviews, and midterm exams. These are scheduled by the individual instructor. Often there are midterm exams about the beginning of fourth and eighth weeks of instruction, plus reviews for the final exam.Tao, T., Analysis II, 3rd Ed., HindustanLectureSectionTopicsMetric Spaces, Some Point-Set Topology and Relative TopologyCauchy Sequences and Completeness, Compact Metric Spaces, Continuous Functions on Metric SpacesContinuity on Product, Connected and Compact Metric SpacesUniform Convergence, Midterm IUniform Convergence and Continuity, the “Sup” Norm, Series of Functions, Uniform Convergence in Integration and Differentiation3Formal Power Series, Real Analytic Functions, Abel’s Theorem (Optional)4, Multiplication of Power SeriesExponential and Logarithmic Functions, Trigonometric Functions, Periodic FunctionsInner Products on Periodic Functions, Trigonometric Polynomials, Hour Exam IIPeriodic Convolutions, L2 convergence of Fourier Series and Plancherel’s Theorem, Differentiability of Functions of Several VariablesThe Several Variable Chain Rule, Clairaut’s Theorem, Review of Course Math 131C: Topics in Analysis Conway, J., A First Course In Analysis, Cambridge University PressCoddington, E., An Introduction to Ordinary Differential Equations, Dover Publications Math 132: Complex Analysis for Applications Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B. Introduction to basic formulas and calculation procedures of complex analysis of one variable relevant to applications. Topics include Cauchy/Riemann equations, Cauchy integral formula, power series expansion, contour integrals, residue calculus.The following schedule, with textbook sections and topics, is based on 26 lectures. The remaining classroom meetings are for leeway, reviews, and a midterm exam. These are scheduled by the individual instructor. Often there are a review and a midterm exam about the end of the fifth week of instruction, plus a review for the final exam.T. Gamelin, Complex Analysis, Springer/Verlag.*The book is subject to change. Check with the UCLA Bookstore.LectureSectionTopicsComplex numbers, polar form, complex multiplication, roots of complex numbers (much of this is review)Elementary functions, including power, root, exponential, logarithm, and trigonometric functionsComplex derivatives, basic rules of differentiationCauchy-Riemann equations; inverse functions; harmonic functions; conformality; fractional linear transformationsReview line integrals and Green’s theorem; harmonic conjugatesComplex line integrals, ML-estimate, fundamental theorem of complex calculusCauchy’s theorem, Cauchy integral formulae, Liouville’s theorem, Morera’s theorem (statement only)Catch up, review, midterm examWeierstrass M-test, power series, radius of convergence, operations on power series, order of zerosLaurent decomposition, isolated singularities, orders of poles and zeros, partial fractions decompositionResidue theory, applications of residue calculus to evaluate integralsArgument principle, location of rootsCatch up, review for final exam. Math 132H: Complex Analysis (Honors) Course DescriptionLecture, three hours; discussion, one hour. Requisites: courses 32B, 33B, and 131A with grades of B or better. This course is specifically designed for students who have strong commitment to pursue graduate studies in mathematics. Introduction to complex analysis with more emphasis on proofs. Honors course parallel to course 132. P/NP or letter grading.Complex Analysis by Stein and Shakarchi.LectureSectionTopicsComplex numbers and the complex plane (Basic properties, convergence, sets in the complex plane); Functionas on the complex plane (continuous functions, holomorphic functions, power series)-Basic properties, convergence, sets in the complex planeGoursat’s theorem; Local existence of primitives and Cauchy’s theorem in a discEvaluation of some integrals; Cauchy’s integral formulasZeros and poles; The residue formulaSingularities and meromorphic functionsThe argument principle and applications; Homotopies and simply connected domains; The complex algorithmConformal equivalence and examples (the disc and upper half-place, further examples, the Dirichlet problem in a strip); The Schwarz lemma and automorphisms of the disc and upper half-place (Automorphisms of the disc, automorphisms of the upper half-place); The Riemann mapping thoerem (Necessary conditions and statement of theorem, Montel’s theorem, proof of Riemann mapping theorem; Conformal mappings onto polygons (Some examples, the Schwarz-Christoffel integral, boundary behavior, the mapping formula, return to elliptic integrals) Math 133: Introduction to Fourier Analysis Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 33A, 33B, 131A. Fourier series, Fourier transform in one and several variables, finite Fourier transform. Applications, in particular, to solving differential equations. Fourier inversion formula, Plancherel theorem, convergence of Fourier series, convolution. P/NP or letter grading.This syllabus is based on a single midterm; instructors who wish to give a second midterm may adjust the syllabus appropriately, or give the second midterm in section. The lecturer may also wish to expand the applications components (lectures 11-12, 22-24, 26-28) or move them earlier in the course.E. Stein and R. Shakarchi, Fourier Analysis: An Introduction (Princeton Lectures in Analysis, Volume 1), Princeton University Press.LectureSectionTopicsReview: Complex numbers (esp. Euler’s formula); periodic functions; functions on an interval; functions on a circle; continuous functions; continuously differentiable functions; Riemann integrable functions (or at least piecewise continuous functions). NoDoes every function have a Fourier series? Formal computation of Fourier coefficients. Inversion formula for trigonometric polynomials. Examples of Fourier series (esp. Dirichlet kernel).Review of convergence, uniform convergence. Do Fourier series converge back to the original function? Injectivity of the Fourier transform for continuous functions.Uniform convergence for absolutely summable Fourier coefficients. Relationship between differentiation and the Fourier transform. Uniform convergence for C^2 functions. (Optional) Some foreshadowing of future convergence results.Convolutions of continuous periodic functions: examples and basic properties. Connections with Fourier coefficients. Connection between partial sums and the Dirichlet kernel.Convolutions of integrable periodic functions: approximation of integrable functions by continuous ones. Approximation via convolution by good kernels.Badness of the Dirichlet kernel; Gibbs’ phenomenon. Cesaro means; Fejer kernel. Fejer’s theorem. Uniform approximation of continuous functions by trigonometric polynomials.Review of vector spaces, inner product spaces, orthonormal sets, Cauchy-Schwarz inequality, Pythagoras’s theorem. Orthonormality of the Fourier basis. Bessel’s inequality. Best mean-square approximation by trigonometric polynomials.Mean-square convergence of Fourier series for continuous functions. Mean-square convergence of Fourier series for Riemann-integrable functions. Plancherel’s theorem, Parseval’s theorem. Riemann-Lebesgue lemma.Applications and further properties of Fourier series, at instructor’s discretion. Some suggestions: Summation of 1/n^2; local convergence of Fourier series at smooth points; smoothness of a function versus decay of Fourier coefficients; a continuous funcFrom Fourier series to Fourier integrals – an informal discussion. Review of improper integrals. Functions of moderate decrease. Functions of rapid decrease. Schwartz functions. Definition of the Fourier transform.Basic algebraic properties of the Fourier transform. Preservation of the Schwartz space.Fourier transform of Gaussians. Gaussians as good kernels.Multiplication formula. Fourier inversion formula. Bijectivity on Schwartz space.Fourier transform and convolutions. Plancherel’s theorem. Extension to functions of moderate decrease.Integration on R^d; Fourier transform on R^d; key properties.Applications to PDE: heat equation; Laplace’s equation. (Optional) The wave equation (in 1D or higher dimensions).Z_N. The finite Fourier transform; key properties.Applications and further properties of Fourier transforms, at instructor’s discretion. Some suggestions: The fast Fourier transform; fast multiplication; Heisenberg uncertainty principle; Comparison of Fourier and Laplace transforms; The Fourier-Bessel tr Math 134: Linear and Nonlinear Systems of Differential Equations Course Description(4) (Formerly numbered 135A.) Lecture, three hours; discussion, one hour. Requisites: course 33B. Dynamical systems analysis of nonlinear systems of differential equations. One- and two- dimensional flows. Fixed points, limit cycles, and stability analysis. Bifurcations and normal forms. Elementary geometrical and topological results. Applications to problems in biology, chemistry, physics, and other fields. P/NP or letter grading.S. Strogatz, Nonlinear Dynamics and Chaos (2nd Ed.), Perseus Books Group.J. Crawford, Introduction to Bifurcation Theory, Reviews of Modern Physics, vol. 63. (Recommended supplement).LectureSectionTopicsDefinition of dynamical systems. Discussion of importance and difficulty of nonlinear systems. Examples of applications giving rise to nonlinear models.Elementary one-dimensional flows. Flows on the line, fixed points, and stability. Application to population dynamics. Discussion of how geometric “dynamical systems” approach is different from approach in Math 33.“Advanced” one-dimensional flows. Linear stability analysis (with numerous examples), existence and uniqueness, impossibility of oscillations.Potentials. Introduction to the idea of numerical solutions of nonlinear equations, including discussion of basic methods, software tools (Matlab, Maple, Mathematica, DSTool, xppaut, etc.). Advertisement for Math 151A/B.Introduction to bifurcations, saddle-node bifurcation. Physical relevance of bifurcations, introduction to bifurcation diagrams, notion of normal forms. For saddle-node bifurcation, incorporate treatment in Crawford.Transcritical bifurcation. Incorporate treatment in Crawford. Extended example on laser threshold.Pitchfork bifurcation. Incorporate treatment in Crawford. Extended example on overdamped bead on rotating hoop.Dimensional analysis. Basic technique. Relate to overdamped bead example.Imperfect bifurcations. Basic theory and bifurcation diagrams. Insect outbreak model, time permitting.Flows on the circle. Definition, beating, nonuniform oscillators, ghosts and bottlenecks.Oscillator examples. Instructor should choose one or two of the examples (overdamped pendulum, fireflies, superconducting Josephson junctions) to cover in depth.Introduction to two-dimensional linear systems. Motivating examples, mathematical set-up, definitions, different types of stability. Phase portraits, stable and unstable eigenspaces.Classification of linear systems. Eigenvalues, eigenvectors. Characteristic equation, trace and determinant. Different types of fixed points. (Suggestion: cover example material in Section 5.3 and related problems on homework.)Introduction to two-dimensional nonlinear systems. Phase portraits and null-clines. Existence, uniqueness, and strong topological consequences for two-dimensions.Equiliria and stability. Fixed points and linearization. Effect of nonlinear terms. Hyperbolicity and the Hartman-Grobman theorem.Special nonlinear systems. Conservative and reversible systems. Heteroclinic and homoclinic orbits.Extended application of nonlinear phase plane analysis to classic pendulum problem without restricting to small-angle regime. (Alternatively: another application of the instructor’s choice.)Index theory. Discussion of local versus global methods. Definition and useful properties of the index, with examples.Introduction to limit cycles. Definition. Polar coordinates. Van der Pol oscillator and other examples.Ruling out limit cycles. Gradient systems, Liapunov functions, and Dulac’s criterion, with examples.Proving existence of closed orbits. Poincare-Bendixson theorem, trapping regions. Examples. Impossibility of chaos in the phase plane.Bifurcations in two (and more) dimensions. Revisitation of saddle-node, transcritical, and pitchfork bifurcations, with examples.Hopf bifurcation. Definition. Supercritical, subcritical, and degenerate types. Application to oscillating chemical reactions if time permits.Global bifurcations of cycles. Saddle-node, infinite-period, and homoclinic bifurcations. Scaling laws for amplitude and period of limit cycle. Math 135: Ordinary Differential Equations Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 33A, 33B. Selected topics in differential equations. Laplace transforms, existence and uniqueness theorems, Fourier series, separation of variable solutions to partial differential equations, Sturm-Liouville theory, calculus of variations, two point boundary value problems, Green’s functions. P/NP or letter grading.G. Simmons, Differential Equations with Applications and Historical Notes, 3rd Ed., McGraw-Hill.LectureSectionTopicsReview of solution methods and properties of solutions for linear constant coefficient equations.Laplace transform. Forward transform, inverse transform. Examples of transform pairs.The Laplace transform of a differential equation. The use of Laplace transforms for the solution of initial value problems.Computation of the inverse Laplace transform. Partial fraction expansions revisited1.Existence and uniqueness of Laplace transforms. Sectionally continuous functions. Exponentially bounded functions.Proof of the convolution theorem. The Heaviside expansion theorem2.The Heaviside function and Dirac distribution. Unit impulse response functions. Use of the unit impulse response function3.Existence and uniqueness theory. Examples of differential equations without unique solutions or global solutions. Lipschitz condition; determination of Lipschitz constants.Statement of a global existence and uniqueness theorem — when f(x,y) is Lipschitz in [a,b] x [-8, 8]4. Examples of the application of the existence and uniqueness theorem.Outline of the proof of existence and uniqueness theorem. Proof preliminaries; max norm, uniform convergence, Weierstrauss M-test. Equivalence of the differential equation to an integral equation5.Picard iteration. Proof of existence and uniqueness.Local existence and uniqueness theorems. Applications of local existence and uniqueness theorems.Periodic functions and Fourier series. The inadequacy of power series approximations for periodic functions. Fourier series coefficient formulas. Examples of Fourier series.Derivation of Fourier series coefficient formulas. Fourier series for periodic functions over arbitrary intervals.Function inner products. Orthogonal functions. Derivation of Fourier series coefficient formulas using inner products.Convergence theorems for Fourier series: Pointwise convergence.Convergence theorems for Fourier series: L2 convergence (Mean convergence).Eigenvalues and Eigenfunctions of two point boundary value problems.Separation of variables solution to one dimensional heat equation.Separation of variables solution to Laplace’s equation in a disk.Sturm-Liouville problems.Calculus of Variations: Introduction.Euler’s differential equation for an extremal. Math 136: Partial Differential Equations Course DescriptionLecture, three hours; discussion,one hour. Prerequisites: courses 33A, 33B. Linear partial differential equations, boundary and initial value problems; wave equation, heat equation, and Laplace equation; separation of variables, eigenfunction expansions; selected topics, as method of characteristics for nonlinear equations.W.A. Strauss, Partial Differential Equations, 2nd Edition, John Wiley and Sons.The course covers Chapters 1, 2, parts of 3, and most of 4-6.LectureSectionTopicsThe notion of a partial differential equation (PDE), the order of a PDE, linear PDE, examples. First order linear PDE.Homogeneous first order linear PDE with constant coefficients. The method of characteristics (geometric method) and the coordinate method. First order linear PDE with variable cofficients. Characteristic curves and the geometric method in the case of variable cofficients. The solvability of the Cauchy problem for a first order linear PDE (the statement only).PDE from Physics. Examples: the heat equation (derivation using Fourier’s law), vibrating strings and drumheads, the wave equation and the Laplace equation. Schrodinger’s equation.Initial and boundary conditions for PDE. Classification of second order linear PDE with constant coefficients. Elliptic and hyperbolic PDE.The wave equation on the real line.Traveling waves. The Cauchy problem for the wave equation and the d’Alembert formula. Examples.The causality principle for the wave equation. The domain of dependence and the domain of influence. Conservation of energy.The diffusion/heat equation on the real line. The maximum principle and the uniqueness of the Dirichlet problem for the heat equation. The heat kernel and the solution of the initial value problem for the heat equation on the real line. The smoothing property of the heat flow and the comparison of the main properties of the wave and heat equations.The heat equation on the half-line. The Dirichlet and Neumann boundary conditions. The method of reflections.The wave equation on the half-line. Reflected waves. (The first part of Section 3.2).The inhomogeneous heat equation on the real line. The inhomogeneous wave equation on the real line and the operator method. Duhamel’s principle. (Section 3.4: the proof of Theorem 1 using the operator method)Review before the midterm.Spectral methods for boundary problems on finite intervals. Separation of variables and the wave equation with Dirichlet boundary conditions. The eigenvalues and eigenfunctions on a bounded interval with Dirichlet boundary conditions. The heat equation with Dirichlet boundary conditions. Formal eigenfunction expansions.The Neumann boundary conditions for the wave and the heat equations. The eigenvalues and eigenfunctions of on a bounded interval with Neumann boundary conditions.The eigenvalues and eigenfunctions on a bounded interval with Robin boundary conditions: a cursory discussion.Fourier series and Fourier coefiicients of periodic functions in real and complex form. Fourier series expansions for functions defined on an interval of the form via even and odd extensions. Since and cosine expansions. Examples.Symmetric boundary conditions and the orthogonality of eigenfunctions. Convergence theorems for Fourier series, the notions of uniform and L^2-convergence. The least square approximation, Bessel’s inequality, and Parseval’s identity. One word about the pointwise convergence of Fourier series.The Laplace equation and harmonic functions. The maximum principle and the uniqueness of the Dirichlet problem. The Laplace operator in polar coordinates and the Newtonian potential in 2D and 3D.The Laplace equation and separation of variables in a rectangle. (Section 6.2, may be omitted due to time constraints).The Dirichlet problem in the disc and Poisson’s formula. The mean value property for harmonic functions and their differentiability properties. Math 142: Mathematical Modeling Course DescriptionLecture, three hours; discussion, one hour. Prerequisites: courses 32B, 33B. Introduction to fundamental principles and spirit of applied mathematics. Emphasis on manner in which mathematical models are constructed for physical problems. Illustrations from many fields of endeavor, such as the physical sciences, biology, economics, and traffic dynamics.Haberman, R., Mathematical Models, Society for Industrial and Applied Mathematics. Math 146: Methods of Applied Mathematics Course DescriptionLecture, three hours; discussion, one hour. Prerequisite: courses 32B, 33B. Integral equations, Green’s function, and calculus of variations. Selected applications from control theory, optics, dynamical systems, and other engineering problems.Troutman, J., Variational Calculus and Optimal Control: Optimization with Elementary Convexity, 2nd Ed., Springer. Math 151A: Applied Numerical Methods Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B, 115A, Program in Computing 10A. Introduction to numerical methods with emphasis on algorithms, analysis of algorithms, and computer implementation issues. Solution of nonlinear equations. Numerical differentiation, integration, and interpolation. Direct methods for solving linear systems. Matlab programming. Letter grading.R. Burden and J. Faires, Numerical Analysis, 10th Ed., Brooks/Cole.LectureSectionTopicsGeneral course overview and machine numbersAlgorithms and convergenceSecant method, and method of False PositionConvergence order. Multiple rootsZeros of polynomials. Horner’s methodDeflation and Lagrange polynomialsLagrange polynomials and Neville’s methodInterpolation nodes and finite differenceCubic spline interpolationForward/backward differenceFinite-difference formulasRichardson’s extrapolation. Interpolation based numerical integrationNewton-Cotes formulas. Composite integration formulasSpecial types of matricesReview of matrix algebra. Jacobi’s method Math 151B: Applied Numerical Methods Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 151A. Introduction to numerical methods with emphasis on algorithms, analysis of algorithms, and computer implementation. Numerical solution of ordinary differential equations. Iterative solution of linear systems. Computation of least squares approximations. Discrete Fourier approximation and the fast Fourier transform. Matlab programming. Letter grading.R. Burden and J. Faires, Numerical Analysis, 10th Ed., Brooks/Cole.LectureSectionTopicsHigher-order Taylor methods. Error analysis of one-step methodsStability of one-step methods. Taylor Theorem in two variablesButcher tableau. Design a Runge-Kutta methodRunge-Kutta-Fehlberg method.Adams-Bashforth/Adams-Moulton multistep methodsPredictor-corrector methods. Analysis of general multistep methodsStability of multistep methods. Stiff differential equationsRegion of absolute stabilityHigh-order differential equations. Systems of differential equationsBoundary value problems. Linear shooting methodNonlinear shooting method. Finite difference methods for linear BVPFinite-difference methods for nonlinear BVPSolving nonlinear systems of equations. Newton’s methodQuasi-Newton method – Broyden’s methodHomotopy and continuation methodsLinear algebra, Eigenvalues, orthogonal matrices and similarity transformationsPower method. Inverse Power methodHouseholder’s transformation. Householder’s methodQR factorization. QR algorithmDiscrete least squares approximation. Linearly independent functionsOrthogonal polynomials and least squares approximationContinuous and discrete trigonometric polynomial approximation.Fast Fourier transform II Math 151AH: Numerical Analysis Part 1 (Honors) Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B, 115A, 131A, Programming in Computing 10A or equivalent. Rigorous introduction to numerical algorithms including necessary skills to apply algorithms in statistics, imaging, data science, engineering and related fields. Root Finding, solving linear systems, interpolation, quadrature and finding eigenvalues. MatLab programming. P/NP or letter grading.Textbook:L. Ridgway Scott, Numerical Analysis, Princeton University Press.General Course Outline/Schedule of Lectures:WeekChapterTopics11, 18Introduction to finite precision arithmetic and algorithms. Convergence and Stability. Floating point numbers, their arithmetic and errors. Big “O” notation.22Fixed-point algorithms. Applications to root-finding. Newton’s method and the secant method. Connections with optimization. Error analysis.35, 6Review of linear algebra. Vector spaces and norms. Infinite dimensional vector spaces. Operators and operator norms. Inner products. Powers and convergence of matrices.43Basic numerical methods for linear systems. Guassian elimination. Triangular matrices and the LU decomposition. Pivoting rules. Cholesky decomposition. Application to banded matrices.58Iterative methods for linear systems. Jacobi and Gauss-Seidel methods. Convergence analysis for these algorithms. Application to sparse linear systems. Matrix splittings in general.67System of nonlinear equations. Functional iteration. Newton’s method and quasi-Newton’s method. Bi-level procedures for fixed point problems.710, 11Polynomial interpolation. Connection to linear systems. Relationship between Taylor polynomials and Lagrange polynomials. Higher order interpolation schemes such as Hermite polynomials. Approximation with trigonometric series.812Introduction to approximation theory. Lebesgue and Sobolev spaces of functions. Weierstrass Thoerem. Bernstein polynomials. Splines. Connection between polynomials approximation and least squares.913Numerical quadrature. “Basic” schemes such as trapezoidal and Simpson’s. Gaussian quadrature. Composite schemes.1014Introduction to eigenvalue problems. Some sample applications. Gershgorin’s disks. Finding all vs. finding highest eigenvalue. Power method. Hessenberg factorizations and finding all eigenvalues. Math 151BH: Numerical Analysis Part 2 (Honors) Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 115A or 115AH, 131A or 131AH, 151A or 151AH, Computer Science 31 or Programming in Computing 10A, with grades of B or better. Rigorous introduction to numerical algorithms including necessary skills to apply algorithms in statistics, imaging, data science, engineering and related fields. Finding eigenvalues, finding numerical solutions to ordinary differential equations, the least squares problem and the fast Fourier transform. MatLab programming. Honors course parallel to course 151B. P/NP or letter grading.Course Objectives1. Students will acquire an understanding of the background theory, the derivation, and the implementation, of foundational methods of numerical approximation.2. Students will learn to analyze concrete problems that arise in practice, and choose and implement appropriate numerical methods for their solution.3. Students will learn how to assess the accuracy of approximations as function of the algorithms employed and the data used.4. Areas covered in 151BH include numerical methods for finding eigenvalues and eigenvector/eigenvalue pairs, methods for numerical solution of ordinary differential equations, including systems and boundary value problems, solution of least squares problems, and elementary Fourier theory, including the Fast Fourier Transform and some of its applications. Textbook:L. Ridgway Scott, Numerical Analysis, Princeton University Press. (LSR)R. Burden and J. Faires, Numerical Analysis, 10th Ed., Cengage. (BF)Grade policy:Homework 40% Midterm 25% Final exam 35%General Course Outline/Schedule of Lectures:WeekChapterTopics1BF: 8.1 – 8.5Brief review of linear algebra. The least squaresproblem. QR decompositions, Householder trans-formations.2BF: 8.1 – 8.5LSR: 9The conjugate gradient method. The Kacsmarzmethod. Ridge regression and LASSO.3LSR: 14Introduction to eigenvalue problems. Some sample applications. Gershgorin’s disks. Finding all vs. finding highest eigenvalue. Power method. Hessenberg fact-orizations and finding all eigenvalues.4LSR: 15Eigenvalue algorithms. Power method, inverse iteration and deflation. Singular Value Decomposition. Finding all eigenvalues using QR decomposition and using Jacobi iteration.5BF: 5.9LSR: 16Ordinary differential equations. Existence and uniqueness of solutions. Euler and implicit Euler methods. Error estimates.6BF: 5.4LRS: 17Systems of differential equations and higher order differential equations. Higher order solvers for initial value problems. Runge-Kutta.7BF: 5.6, 5.10, 5.11Stability for numerical ODE solvers. Implicit schemes such as Adams-Moulton. Multi-step and predictor corrector schemes. Stability.8BF: 11.1 – 11.4Boundary value problems. Linear and nonlinear shooting methods. Finite difference methods.9BF 8.5, 8.6Trigonometric polynomial approximation. Elementary Fourier theory. The fast Fourier trans-form.10Review and catch-up. Math 155: Mathematical Imaging Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33B, 115A, Program in Computing 10A. Imaging geometry. Image transforms. Enhancement, restoration, and segmentation. Descriptors. Morphology. P/NP or letter grading.R. Gonzalez and R. Woods, Digital Image Processing, New edition, Prentice-Hall. Book is Subject to Change Without Notice.LectureSectionTopicsIntroduction: A Simple image model (2.2); Sampling and Quantization (2.3)Introduction to the Fourier TransformThe Discrete Fourier TransformSome Properties of the Two-Dimensional Fourier TransformSome Properties of the Two-Dimensional Fourier TransformThe Fast Fourier TransformOther Separable Image TransformsOther Separable Image TransformsEnhancement by Point ProcessingEnhancement by Point ProcessingEnhancement in the Frequency DomainImage Restoration: Degradation ModelDetection of DiscontinuitiesEdge Linking and Boundary DetectionRegion-Oriented SegmentationThe Use of Motion in Segmentation Math 156: Machine Learning Course DescriptionLecture, three hours; discussion, one hour. Requisite: course 115A, 164, 170E (or 170A or Statistics 100A)

and Programming in Computing 10A of Computer Science 31. Strongly recommended requisite: Program in Computing 16A or Statistics 21. Introductory course on mathematical models for pattern recognition and machine learning. Topics include parametric and nonparametric probability distributions, curse of dimensionality, correlation analysis and dimensionality reduction, and concepts of decision theory. Advanced machine learning and pattern recognition problems, including data classification and clustering, regression, kernel methods, artificial neural networks, hidden Markov models, and Markov random fields. Projects in MATLAB to be part of final project presented in class. P/NP or letter grading.?Pattern Recognition and Machine Learning?, by Christopher M. Bishop, Springer, 2006 (ISBN-13: 978-0387-31073-2), plus complementary sources where necessary (?n/a?).LectureSectionTopicsIntroduction, Definitions, Pre-requisites. Course Introduction, recap on Linear Algebra, probabilities. Gaussian, exponential pdf; Learning parametric pdf. Learning non-metric pdf.Correlation Analysis, dimensionality reduction, PCA. PCA: maximum variance, minimum error, high-dimensional PCA. Probabilistic PCA (ML-PCA, EM, Bayesian PCA). Non-linear latent variable models: ICA, kPCARegression. Linear Basis Function Models, least squares and maximum likelihood. Bayesian linear regression. Evidence Approximation.Classification. Discriminant functions; least squares. Logistic regression. Mixture of linear classifiers: Boosting and Bagging.Clustering. K-Means, Gaussian mixture model, Expectation-Maximization, Spectral clustering.Kernel methods. Dual representation, kernel trick; Constructing kernels. Gaussian processes, GP regression, GP classification. Support vector machines, k-SVM.Artificial neural networks. Biological motivation; the perceptron; Feed-forward Network. Single Layer network training. Multi-layer perceptron training: Backpropogation.Markov models. Bayesian Networks. Markov Random Fields; Iterated conditional modes (SA, graph-cuts). Hidden Markov Models; forward-backward, Viterbi algorithm.Advanced Topics (optional). Reinforcement learning, Bellman optimality. Vapnik-Chervonenkis (VC) dimension; overfit and underfit. Probably approximately correct (PAC) learning.Leeway (to accommodate midterm and holidays in the preceding weeks). Review. Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A, 131A. Not open for credit to students with credit for Electrical Engineering 136. Fundamentals of optimization. Linear programming: basic solutions, simplex method, duality theory. Unconstrained optimization, Newton's method for minimization. Nonlinear programming, optimality conditions for constrained problems. Additional topics from linear and nonlinear programming. P/NP or letter grading.The following schedule, with textbook sections and topics, is based on 27 lectures. The remaining classroom meetings are for leeway, reviews, and a midterm exam. These are scheduled by the individual instructor.E. K.P. Chong and S. Zak, An Introduction to Optimization, 4th Edition, Wiley.LectureSectionTopicsReview vector space, transforms geometry, calculusOptimization models, constraintsFeasible set, feasible directionsGradient methods, steepest descent methodAnalysis of gradient methodsNewton's methodModified Newton's methodThe Conjugate Direction methodsQuasi-Newton MethodsMidtermSolving Linear equationsIntro. to linear programming, polyhedronLinear programming Simplex methodNonlinear optimization with equality constraintsNonlinear optimization with inequality constraintsAlgorithms for constrained optimizationCatch-up, Review Math 167: Mathematical Game Theory Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 115A. Quantitative modeling of strategic interaction. Topics include extensive and normal form games, background probability, lotteries, mixed strategies, pure and mixed Nash equilibria and refinements, bargaining; emphasis on economic examples. Optional topics include repeated games and evolutionary game theory. P/NP or letter grading.LectureSectionTopicsExample and graphical solutionMake epicit definitio in 2×2 case and minmax. Minmax StatementNash equilibria (mutual best responses)Proof of minmax: assume separating hyperplane theorem and derive proof. Do planar n by 2 case first with pictures.Prove separating hyperplanesWork on good problems in classIntroduce non-cooperative (aka general sum) gameBasic 2 x 2 examples (PD, Dove-Hawk, etc.)Solve two- player NE's (2×2, 3×3 case)Beginning of proof of NE's: definition of a convex correspondence.Proof NE's exist based on Kakutani (convex correspondences have fixed points)Price of Anarchy, Chapter 8Stable matching, Chapter 10 Math 168: Introduction to Networks Course Description (4) Lecture, three hours; discussion, one hour. Requisites: courses 115A, 170A or Electrical and Computer Engineering 131A or Statistics 100A. Introduction to network science (including theory, computation, and applications), which can be used to study complex systems of interacting agents. Study of networks in technology, social, information, biological, and mathematics involving basic structural features of networks, generative models of networks, network summary statistics, centrality, random graphs, clustering, and dynamical processes on networks. Introduction to advance topics as time permits. P/NP or letter grading. Students will develop a sound knowledge and appreciation of some of the tools, concepts, and computations used in the study of networks. The study of networks is predominantly a modern subject, so the students will also be expected to develop the ability to read and understand current research papers in the field. They will also have a chance to explore a topic in depth in a final project. Topics include: basic structural features of networks, generative models of networks, centrality, random graphs, clustering, and dynamical processes on networks. Mark E. J. Newman, Networks 2nd Edition, 2018 [primary text]Mason A. Porter and James Gleeson, Dynamical Systems on Networks: A Tutorial, 2016Supplementary material from survey, review, and tutorial articles. Lecture Section Topics Introduction and Basic Concepts Models of Network Formation Newman 7 + supplementary material Network Summary Statistics Newman 11 + supplementary articles Newman 16-18; Porter & Gleeson Dynamical Processes on Networks Introduction to Advanced Topics Math 170A: Probability Theory I Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 32B, 33A, 131A. Not open to students with credit in course 170E, Electrical Engineering 131A or Statistics 100A. Rigorous presentation of probability theory based on real analysis. Probability space, probability and conditional probability, independence, Bayes?' rule, discrete and continuous random variables and their distributions, expectation, moments and variance, conditional distribution and expectation, weak law of large numbers. P/NP or letter grading.The course discusses the fundamentals of probability as a mathematical discipline rooted in undergraduate real analysis. At the end of the course, the students will have the tools and ability to formulate, analyze an answer questions in probability and prove the validity of their reasoning in full mathematical rigor.Probability: An Introduction (2nd ed.). by Grimmett, G. R., & Welsh, D. J. (2014).Oxford: Oxford University Press.Outline update: T. Austin, 01/20LectureSectionTopicsSample space, events, probabilityConditional probability and independencePartition theorem and Bayes rule, examplesDiscrete random variables, their functions, expectation and varianceConditional expectation, multivariate discrete distributionsIndependent discrete random variables, indicatorsCumulative distribution function, continuous random variablesMultivariate distributions and their marginalsChange of variables, conditional expectationSections 6.8, 7.3, 8.1-8.2Multivariate normal distribution, weak law of large numbers Math 170B: Probability Theory Course Description(4) Lecture, three hours; discussion, one hour. Enforced requisite: courses 170A, 131A. Continuation of rigorous presentation of probability theory based on real analysis. Moments and generating functions; laws of large numbers, the central limit theorem, and convergence in distribution; branching processes; random walks; Poisson and other random processes in continuous time. Advance topics in probability theory. P/NP or letter grading.Probability: An Introduction (2nd ed.). Oxford: Oxford University Press. by Grimmett, G. R., & Welsh, D. J. (2014).LectureSectionTopicsReview from 170A: probability spaces, random variables, and distributions; multi-variate distributions and independence; discrete and continuous conditional probabilityMoments, probability and moment generating functions, characteristic functionsInequalities. Laws of large numbers. The central limit theorem. Convergence in distribution.Branching processes and the method of generating functions, probability of extinctionRandom walks on the integers: recurrence vs transience, gambler's ruinPoisson processes and their inter-arrival times. Population growth, birth processesBirth-and-death processes, queueing models Math 170E: Introduction to Probability and Statistics: Part 1 Probability Course DescriptionLecture, three hours; discussion, one hour. Requisites: courses 31A, 31B. Not open to students with credit for course 170A, Electrical and Computer Engineering 131A, or Statistics 100A. Introduction to probability theory with emphasis on topics relevant to applications. Topics include discrete (binomial, Poisson, etc.) and continuous (exponential, gamma, chi-square, normal) distributions, bivariate distributions, distributions of functions of random variables (including moment generating functions and central limit theorem). P/NP or letter grading.Hogg, Tanis, Zimmerman Probability and Statistical Inference (10th Edition)LectureSectionTopicsBasic Properties of ProbabilityDiscrete Random VariablesNegative Binomial DistributionContinuous Random VariablesExamples: exponential, Gamma, Chi-squareMidterm on Chapters 1 and 2Add'l models: failure rate, mortality, insuranceDiscrete bivariate distributionsConditional DistributionsContinuous Bivariate DistributionsBivariate Normal DistributionFunctions of a random variableTransformations of 2 random variablesMoment generating functionsRandom functions associated to normal distributionsApproximations for Discrete distributionsChebyshev's inequality and convergence in probability Math 170S: Introduction to Probability and Statistics: Part 2 Statistics Course DescriptionLecture, four hours. Requisites: courses 31A, 31B, and 170E. The Math 170E and 170S two quarter probability and statistics sequence is aimed to equip Math-Econ and Financial Actuarial majors with essential skills in these areas. Math 170S is an introduction to statistics. Topics include sampling; estimation and the properties of estimators; construction of confidence intervals and hypotheses testing. It is designed to meet the Society of Actuaries' VEE Requirements for Mathematical Statistics. Letter grading.Hogg, Tanis, Zimmerman Probability and Statistical Inference (10th Edition)LectureSectionTopicsExploratory Data AnalysisMaximum Likelihood EstimationA Simple Regression ProblemConfidence Interval for MeansConfidence Intervals for the Difference of Two MeansConfidence Interval for ProportionsDistribution-Free Confidence Intervals for PercentilesMidterm 1 on Chapter 6 and 7Tests of the Equality of Two meansPower of a Statistical TestChi-Square Goodness-of-Fit TestsOne-Factor Analysis of VarianceTwo-Way Analysis of Variance Math 171: Stochastic Processes Course Description(Formerly numbered 151.)Lecture, three hours; discussion, one hour. Requisites: courses 33A, 170A (or Statistics 100A). Discrete Markov chains, continuous-time Markov chains, renewal theory. P/NP or letter grading. Math 174E: Mathematics of Finance for Mathematics/Economics Students Course Description(Formerly numbered 174.) Lecture, three hours; discussion, one hour. Enforced requisites: courses 33A, and 170E or Math 170A or Statistics 100A). Not open for credit to students with credit for course 174A, Economics 141, or Statistics C183/C283. Mathematical modeling of financial securities in discrete and continuous time. Forwards, futures, hedging, swaps, uses and pricing (tree models and Black-Scholes) of European and American options, Greeks and numerical methods. P/NP or letter grading.Hull, John C., Options, Futures and Other Derivatives, 10th Edition. Pearson 2018.LectureSectionTopicsForwards, Futures, Options; Types of Traders; Examples of positions.Hedging Using Futures, Interest Rates (zero, forward, term structure) Bonds (duration, convexity)Swaps, Mechanics of Option Markets, Basic Properties of Stock Options (Put-Call Parity, Upper and Lower Bounds for Prices, Effect of Dividends)Binomial Tree Model of Option Pricing (include Proof in Appendix of Black Scholes model)Wiener Process (Brownian Motion) and Ito?s Lemma (include proof as per Appendix)Black-Scholes model (include risk neutral derivation in appendix)Instructor Choice: Do topics from Chapter 17 (Options on Stock Indices and Currencies) and Chapter 20 Volatility Smiles (Concerns deviation of real-world pricing from Black-Scholes model).Basic Numerical Procedures Math 177: Theory of Interest and Applications Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 32B. Types of interest, time value of money, annuities and similar contracts, loans, bonds, portfolios and general cash flows, rate of return, term structure of interest rates, duration, convexity and immunization, interest rate swaps, financial derivatives, forwards, futures, and options. Letter grading.An introductory course on financial mathematics, Math 177 lays the foundation and prepares students for the series of courses required for the Financial Mathematics (FM) exam for the Society of Actuaries (SOA), two lectures before the midterms will be devoted to analysis of complex FM exam problems. While the basic ideas are mathematically elementary, their applications can be complex. The class is suitable for students who seek a career in financial engineering, the actuarial field, banking, etc., or are seeking to improve their financial literacy in a highly quantitative way.Broverman, Samuel A. Mathematics of Investment and Credit. 7th ed., Actex Publications, 2017.Bean, Michael A. (FSA, CERA FCIA, FCAS, PHD). Determinants of Interest Rates. Society of Actuaries, 2017. Education and Examination Committee of the Society of Actuaries – Financial Mathematics Study Note. Robert (ASA, MAAA). Using Duration and Convexity to Approximate Change in Present Value. Society of Actuaries, 2017. Education and Examination Committee of the Society of Actuaries – Financial Mathematics Study Note.
��Beckley, Jeffrey (FSA, MAAA). Interest Rate Swaps. Society of Actuaries, 2017. Education and Examination Committee of the Society of Actuaries – Financial Mathematics Study Note.Https://www.soa.org/Files/Edu/2017/fm-interest-rate-swaps.pdfLectureSectionTopicsSimple, compound, nominal and effective interest rates. Accumulation. Equation of value, actuarial notation.Effective and nominal discount rates, force of interest.Determinants of interest rates.Non-constant payments and other generalizations.Yield and reinvestment rates, depreciation.Determination of bond prices and amortization of a bond.Examples of bonds and applications.Internal rate of return defined and net present value.Other methods (dollar-weighted and time weighted) and examples of rate of return.Advanced problem analysis from Weeks 1-4.Advanced problem analysis from Weeks 1-4.Basic definitions, spot rates.Applications and examples of arbitrage, forward rate agreements and at-par yield.Macaulay duration and modified duration.Application to valuation of cash flows, dependence on term structure.Convexity and immunization.Definitions, determining swap rate.Case of constant notional amount, net payments.Advanced problem analysis from Weeks 6-8.Advanced problem analysis from Weeks 6-8.Derivatives, dividend discount model, short sale of stock, equity investments, financial derivatives. Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 32B, 175 or 177, 170A or 170E or Statistics 100A. An introductory course on the mathematics associated with long term insurance coverages. Single and multiple life survival models, annuities, premium calculations and policy values, reserves, pension plans and retirement benefits. Letter grading.A core sequence course for the Financial Actuarial Mathematics major, Mathematics 178A and the first half of Mathematics 178B cover the syllabus of the Society of Actuaries (SOA) Long Term Actuarial Mathematics (LTAM) exam. By the end of this course, students will be able to value and set premiums for insurance instruments of numerous types using traditional actuarial models. They will also understand the typical models of life contingencies which are used in the calculations.Dickson, David C.M., Hardy, Mary R. and Waters, Howard R, Actuarial Mathematics for Life Contingent Risks. 2nd ed., Cambridge University Press, 2013.LectureSectionTopicsLife insurance and annuity contracts, pension benefits, mutual and proprietary insurers.Future lifetime random variable.First actuarial notation and basic properties of TX.Curtate future lifetime, further discussion and exercises.Life tables, fractional age assumptions.National life tables, survival models for life insurance holders, survival models for life insurance underwriting.Select and ultimate survival models, select life tables.Heterogeneity in mortality, mortality trends and sample problems.Whole life insurance (continuous, annual, 1/m-thly case).Recursions, term insurance, pure endowment and endowment insurance.Deferred insurance benefits, uniform distribution of deaths assumption, claims acceleration approach.Pure endowment, endowment insurance, deferred insurance benefits.Advanced problem analysis.Whole life annuity due, whole life continuous, term continuous, payable 1/ m-thly cases, comparison by payment frequency.Deferred, guaranteed, increasing cases.Evaluating annuity functions, recursions, applying UDD assumption, Woolhouse?s formula.Present value of future loss random variable.Portfolio percentile maximum principle, extra risks.Policies with annual cash flows, future loss random variable.Case of policies with annual cash flows.Recursive formulas for policy values.Annual profit by source, case of policies with cash flows at 1/m-thly.Case of continuous cash flows.Negative policy values, deferred acquisition expenses and modified premium reserves, net premium approach. Course Description(4) Lecture, three hours; discussion, one hour. Requisite: 170S (or 170B or Statistics 100B), 178A. The second of the three quarter sequence 178ABC. Multiple state models, pensions, health insurances, profit testing. Topics in statistics used in actuarial work: methods of estimation and probability distributions. Letter grading.Mathematics 178A and the first half of Mathematics 178B will almost completely cover the syllabus of the Long-Term Actuarial Mathematics exam by the Society of Actuaries. At the end of Mathematics 178A, students learned to value and set premiums for different types of insurances using traditional actuarial models. Mathematics 178B first extends this work to multistate models and then covers pensions, health insurances, and profit-testing. The last three weeks of the course will cover the probability distributions employed in most common actuarial theory and begins the study of the Short Term Actuarial Mathematics syllabus by the Society of Actuaries.(DHW)Dickson, David C.M., Hardy, Mary R. and Waters, Howard R., Actuarial Mathematics for Life Contingent Risks. 2nd ed., Cambridge University Press, 2013.(Hardy)Hardy, Mary R., Long-Term Actuarial Mathematics Study Note. Society of Actuaries, 2017. Education and Examination Committee of the Society of Actuaries – Long Term Actuarial Mathematics Supplementary Note. KPW)Klugman, Stuart A., Panjer, Harry H. and Willmot, Gordon E., Loss Models: From Data to Decisions. 3rd Edition, Wiley, 2012.LectureSectionTopicsExamples, assumptions and notations of multiple state models.Probability formulae and computations, Kolmogorov equations, premiums.Policy values, Thiele?s Differential EquationMultiple decrement modelsMultiple decrement tablesDisability income, long term care, critical illness insurance, continuing care communitiesMortality improvement modellingJoint life and last survivors benefits, independent future lifetimesIndependent future lifetimes (cont.), multiple state model for independent future lifetimesModel with dependent future lifetimes, common shock modelSalary scale function, DC contributionIntroduction to profit testing and principlesProfit measures. Using profit test to calculate premium and reserves, case of multiple state modelsBasic distributions (moments, percentiles, generating functions and sums of random variables)Tails and their classificationsMeasures of risk (value at risk, tail value at risk)Continuous actuarial models, background probabilityExamples of continuous models, creating new distributionsRelations between distributions. Linear exponential familyPoisson and negative binomial distributionsBinomial distributions and (a, b,0) classTruncation and modification at 0 Math 178C: Foundations of Actuarial Mathematics: Loss mode Course Description(4) Lecture, three hours; discussion, one hour. Requisite: 178B. This course is the third of the three quarter sequence 178ABC. 178C studies loss models associated with actuarial problems. It covers severity, frequency, and aggregate loss models, parameter estimation (frequentist, Bayesian), model selection and credibility. Letter grading.The three quarter sequence 178ABC is the actuarial core of the FAM major. 178C covers topics associated with short term actuarial risk. With 178B, most of the topics 1-7 on the SOA STAM exam are covered.S. Klugman, H. Panjer, G. Willmot, Loss Models: From Data to Decisions. 3rd Edition, Wiley, 2012.Hardy, Mary R., Long-Term Actuarial Mathematics Study Note. Society of Actuaries, 2017.Education and Examination Committee of the Society of Actuaries – Long Term Actuarial Mathematics Supplementary Note. elimination ratio, policy limitsCoinsurance, deductibles, limits, impact of deductibles on claim frequencyIntroduction to aggregate loss models and model choiceOther closed form resultsKPW 9.5, 9.6-9.6.5 (exclude 9.6.1)Recursive method, arithmetic discretizationEffect of modifications and individual risk modelEmpirical distributions, grouped dataApproximations for large data setsMaximum likelihood estimation of decrement probabilitiesEstimation of transition intensitiesMaximum likelihood estimationNon-normal confidence intervals and exercisesFrequentist estimation: Poisson and negative binomial casesBinomial and (a, b,1) cases and effect of exposureBayesian inference and predictionModel selection: introductory conceptsConditional Distributions Math 179: Advanced Topics in Financial Mathematics Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 174E. Continuation of Mathematics of Finance. In depth study of risk measures and the instruments of risk management in investment portfolios and corporate financial structure. Exotic and real options, value at risk, mean-variance analysis, portfolio optimization, risk analysis, capital asset pricing model, market efficiency and the Modigliani-Miller theory. P/NP or letter grading.Hull, J. Options., Futures and Other Derivatives, 10th edition. Pearson, 2018.Berk, J. and P. DeMarz., Corporate Finance, 4th edition. Pearson, 2017.White, Toby AMeasures of Investment Risk, Monte Carlo Simulation, and Empirical Evidence on the Efficient Markets Hypothesi Society of Actuaries, 2018. Education and Examination Committee of the Society of Actuaries ? Investment and Financial Markets Study Note. p.221-2, p.237-8, p.249, p.343-5, p.460-3Effect of Dividends on stock prices and option valuesHull 26.1-26.3, p.598-600Hull 26.4-26.7, p.601-603Hull 26.8-26.11, p.603-609Hull 26.12-26.14, p.609-612Hull 22.1-22.3, p. 494-504Hull 22.4-22.6, p. 504-512Hull 22.7-22.9, p. 512-517Value at RiskSecond Reading: White, SOA Study Note IFM 21-18, Sections 1 and 2Hull 28.1-28.3, p. 655-660Hull 35.1-35.3, p. 792-796Hull 35.4-35.5, p. 796-803Berk & DeMarzo 10.1-10.4, p. 318-335Risk, Return, DiversificationBerk & DeMarzo 10.5-10.8, p. 335-350Risk, Return, DiversificationBerk & DeMarzo 11.1-11.3, p. 357-369Portfolio Optimization: Variance and CovarianceBerk & DeMarzo 11.4-11.5, p. 369-381Portfolio Optimization: Risk versus ReturnBerk & DeMarzo 11.6-11.8, p. 381-395Efficient Portfolio, Capital Asset Pricing Model and Risk PremiumBerk & DeMarzo 12.1-12.2, p. 404-413Cost of Capital: Equity Cost and Market PortfolioBerk & DeMarzo 12.3-12.4, p. 407-420Beta Estimation and Debt Cost of CapitalBerk & DeMarzo 12.5-12.7, p. 420-433Project Cost and Project RiskSecond Reading: White, SOA Study Note IFM 21-18, p. 1-7Berk & DeMarzo 13.1-13.4, p. 445-455Role of Investor BehaviorBerk & DeMarzo 13.5-13.6, p. 456-469Market Portfolio and EfficiencyBerk & DeMarzo 13.7-13.8, p. 469-479Multifactor Models of RiskSecond Reading: White, SOA Study Note IFM 21-18, p. 1-7Berk & DeMarzo 14.1-14.2, p. 487-498Modigliani-Miller: Equity vs. Debt FinancingBerk & DeMarzo 14.3-14.5, p. 498-511Leverage, Risk, Cost of CapitalBerk & DeMarzo 8.5, p. 258-265Project Analysis: Sensitivity, Break-Even, ScenarioSecond Reading: White, SOA Study Note IFM 21-18, p. 7-18Berk & DeMarzo 16.1-16.3, p. 551-561Default, Bankruptcy, and DistressBerk & DeMarzo 16.4-16.6, p. 562-575Optimal Capital Structure and LeverageBerk & DeMarzo 16.7-16.9, p. 575-588Agency Costs and Asymmetric Information Course Description(4) Lecture, three hours; discussion, one hour. Requisites: courses 31A, 31B, and 61. Strongly recommended preparation: 115A. Graphs and trees. Planarity, graph colorings. Set systems. Ramsey theory. Random graphs. Linear algebra methods. Ideal for students in computer science and engineering. P/NP or letter grading.The following schedule, with textbook sections and topics, is based on 25 lectures. The remaining classroom meetings are for leeway, reviews, and midterm exams. These are scheduled by the individual instructor. Often there are reviews and midterm exams about the beginning of the fourth and eighth weeks of instruction, plus reviews for the final exam.J. Matousek and J. Nesetril, Invitation to Discrete Mathematics, 2nd Ed., OxfordLectureSectionTopicsBasic counting methods (induction, pigeonhole principle).Graphs, subgraphs, graph isomorphism. Connectivity. Score.Eulerian graphs, diagrams. Hamiltonian cycles. 2-connected graphs.Trees, their characterizations, isomorphism. Minimal spanning tree problem.Planar graphs. Euler's formula. Examples of non-planar graphs. Five color theorem.Sperner's Lemma. Set systems. Sperner's theorem via LYM inequality.Probabilistic method (expectation, independence). 2-Colorings. Random sorting. Turan's theorem.Ramsey's theorem (upper bound, lower bound).Linear algebra methods. Cycle space of a graph. Graham-Pollak theorem. Matrix tree theorem.Probabilistic checking. Finite projective planes. Applications to graphs with no 4-cycles. Course Description(4) Lecture, three hours; discussion, one hour. Requisite: course 3C or 32A and 61. Lecture, three hours; discussion, one hour. Requisite: course 3C or 32A, and 61. Not open for credit to students with credit for Computer Science 180. Graphs, greedy algorithms, divide and conquer algorithms, dynamic programming, network flow. Emphasis on designing efficient algorithms useful in diverse areas such as bioinformatics and allocation of resources. P/NP or letter grading.Kleinberg, Tardos: Algorithm Design, Addison WesleyLectureSectionTopicsIntroduction, Stable Marriage Problem, Gale-Shapley algorithm.Orders of magnitude (Big O notation). Estimating the running time for simple algorithms looking up an entry in a sorted list, mergesort.Basic graph definitions. Directed graphs, trees, paths. Data structures as graphs: stacks, heaps. Breadth first search, Depth First search, test of bipartiteness, DAG's.Introduction to the four main classes of algorithms: Greedy, Divide and Conquer, Dynamic programming, Network Flow. Application of greedy algorithms to interval scheduling and shortest path problems, minimum spanning trees.Divide and conquer algorithms. Mergesort, counting inversions, closest pairs of points. Recurrences.Dynamic programming, weighted interval scheduling, Knapsack problems.Dynamic programming continued, RNA secondary structures, sequence alignment.Network flow: Maximum flow problem. Min cuts. Circulations.Network flow: Airline scheduling, Image segmentation, Project selection.Introduction to P and NP. Math 184: Enumerative Combinatorics Course Description(Formerly numbered 180.) Lecture, three hours; discussion, one hour. Requisite: courses 31A, 31B, 61 and 115A. Permutations and combinations, counting principles, recurrence relations and generating functions. Application to asymptotic and probabilistic enumeration. Ideal for students in mathematics and physics. P/NP or letter grading.M. Bona, Introduction to Enumerative Combinatorics , 2nd Ed., Chapman and Hall/CRCLectureSectionTopicsBasic counting methods (induction, pigeonhole principle).Binomial coefficients, multinomial coefficients, set partitions, Stirling numbers.Integer partitions, partitions into odd and distinct numbers. Euler's Pentagonal theorem.Ordinary and exponential generating functions.Permutations, Number of cycles and descents. Derangements via Inclusion-Exclusion Principle.Inversions. Counting permutation by a cycle type.Counting labelled trees. Different proofs of Cayley's formula.Catalan numbers. Plane and binary trees.Chromatic polynomial. Enumerations of connected graphs and Eulerian graphs.Sequences. Unimodality. Log-concavity. Math 189HC: Honors Contracts Course Description(1) Tutorial, three hours. Limited to students in College Honors Program. Designed as adjunct to upper-division lecture course. Individual study with lecture course instructor to explore topics in greater depth through supplemental readings, papers, or other activities. May be repeated for maximum of 4 units. Individual honors contract required. Honors content noted on transcript. Letter grading. Math 191: Variable Topics Research Seminars: Mathematics Course Description(Formerly Math 197). Seminar, three hours. Math 191 is a variable topics research course in mathematics. Courses will cover material not covered in the regular mathematics upper division curriculum. Reading, discussion, and development of culminating project. May be repeated for credit with topic and/or instructor change. P/NP or letter grading. Math 191H: Honors Research Seminars: Mathematics Course Description(Formerly Math 190). Math Seminar, three hours. Participating seminar on advanced topics in mathematics. Content varies from year to year. May be repeated for credit by petition. P/NP or letter grading. Math 195: Community Internships in Mathematics Education Course DescriptionTutorial, to be arranged. Limited to juniors/seniors. Internship to be supervised by Center for Community Learning and Mathematics Department. Students meet on a regular basis with instructor, provide periodic reports of their experience, have assigned readings on mathematics education, and complete final paper. The final paper is a substantial part of course, and will require a significant investment of time during the quarter. May not be repeated and may not be applied toward major requirements. Individual contract with supervising faculty member required. P/NP grading. Math 197: Individual Studies in Mathematics Course Description(2 to 4 units). Tutorial, three hours per week per unit. Limited to juniors/seniors. At discretion of chair and subject to availability of staff, individual intensive study of topics suitable for undergraduate course credit but not specifically offered as separate courses. Scheduled meetings to be arranged between faculty member and student. Assigned reading and tangible evidence of mastery of subject matter required. May be repeated for maximum of 12 units, but no more than one 197 or 199 course may be applied toward upper division courses required for majors offered by Mathematics Department. Individual contract required. P/NP or letter grading. Math 199: Directed Research or Senior Project in Mathematics Course Description(2 or 4 units). Tutorial, three hours per week per unit. Limited to juniors/seniors. Supervised individual research under guidance of faculty mentor. Scheduled meetings to be arranged between faculty member and student. Culminating report required. May be repeated for maximum of 12 units, but no more than one 197 or 199 course may be applied toward upper division courses required for majors offered by Mathematics Department. Individual contract required. P/NP or letter grading.

Factoring a Difference Between Two Squares Worksheet; Factoring A GCF From an Expression Lesson. ... You can compare your answers against the answer key and even see step-by-step solutions for each problem. ... The Remainder Theorem. Logarithms. Square Roots and Radicals. Rationalization. Rational Expressions. Conic Sections. Study guide for college pre bio exam 9th grade, holt geometry finals cheat sheet, Answers McDougal Littell worksheet answers final exam, practice test online for math b regents. Graphing calculater, factor polynomial cubed, fifth grade math practice test ratios and percentages, understanding order of operation math problems, how to add subtract and divide percentage. Figure 1.4.6. Video presentation of this example. Graphing \(y=x^2 - 6 x\) as an example of \(y = a x^2 + b x + c\) over the domain \(-10 \le x \le 10\text{,}\) but with the ability to easily change the domain of the graph.. Often, when we graph, we will want to change the domain of the graph. Most easily, I may want to zoom in on a particular region to get a better view of some ... Gina wilson all things algebra 2014 triangle congruence asa and aas Questions and Answers (488,240) Quizzes ... Quiz & Worksheet for Kids . View Quiz. ... Elements of the Intermediate Value Theorem . Questions and Answers (488,240) Quizzes ... Quiz & Worksheet for Kids . View Quiz. ... Elements of the Intermediate Value Theorem . PRE-ALGEBRA WITH PIZZAZZ! worksheet answers ; download discrete mathematics and its applications sixth edition solutions ; boolean algebra software ti 89 ; fifth grade fraction practice sheets with answers ; 8th grade charts worksheets ; addition 25 problems worksheet free ; finding gcf and lcm on graphing calculator ; dividing fractions with ... Figure 1.4.6. Video presentation of this example. Graphing \(y=x^2 - 6 x\) as an example of \(y = a x^2 + b x + c\) over the domain \(-10 \le x \le 10\text{,}\) but with the ability to easily change the domain of the graph.. Often, when we graph, we will want to change the domain of the graph. Most easily, I may want to zoom in on a particular region to get a better view of some ... 31.07.2022 · The latest tweets from @Sciemce_Course 3 chapter 5 test form 2a answers - ...About Clutch Scime Answers . About Flats Fort Lake Prater Loudon . C. Many applicants wonder if their U. Get help with your science homework! Access answers to tons of science questions explained in a way that's simple and easy for you to understand. In her first ... Study guide for college pre bio exam 9th grade, holt geometry finals cheat sheet, Answers McDougal Littell worksheet answers final exam, practice test online for math b regents. Graphing calculater, factor polynomial cubed, fifth grade math practice test ratios and percentages, understanding order of operation math problems, how to add subtract and divide percentage. 2,000,000+ Questions and Answers ... Elements of the Intermediate Value Theorem . ... 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This section is a collection of lessons, calculators, and worksheets created to assist students and teachers of algebra. Here are a few of the ways you can learn here... Intermediate Algebra Problems With Answers - sample 2:Find equation of line, domain and range from graph, midpoint and distance of line segments, slopes of perpendicular and parallel lines. Intermediate Algebra Problems With Answers - sample 3 : equations and system of equations, quadratic equations, function given by a table, intersections of lines, problems. Study guide for college pre bio exam 9th grade, holt geometry finals cheat sheet, Answers McDougal Littell worksheet answers final exam, practice test online for math b regents. Graphing calculater, factor polynomial cubed, fifth grade math practice test ratios and percentages, understanding order of operation math problems, how to add subtract and divide percentage. 2,000,000+ Questions and Answers ... Elements of the Intermediate Value Theorem . ... 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We offer a great deal of really good reference information on topics starting from a quadratic to rationalizing Algebra Help. This section is a collection of lessons, calculators, and worksheets created to assist students and teachers of algebra. Here are a few of the ways you can learn here... Figure 1.4.6. Video presentation of this example. Graphing \(y=x^2 - 6 x\) as an example of \(y = a x^2 + b x + c\) over the domain \(-10 \le x \le 10\text{,}\) but with the ability to easily change the domain of the graph.. Often, when we graph, we will want to change the domain of the graph. Most easily, I may want to zoom in on a particular region to get a better view of some ... Questions and Answers (488,240) Quizzes ... Quiz & Worksheet for Kids . View Quiz. ... Elements of the Intermediate Value Theorem . Intermediate Algebra Problems With Answers - sample 2:Find equation of line, domain and range from graph, midpoint and distance of line segments, slopes of perpendicular and parallel lines. Intermediate Algebra Problems With Answers - sample 3 : equations and system of equations, quadratic equations, function given by a table, intersections of lines, problems. 28.01.2018 · For problems 13 – 15 use the Intermediate Value Theorem to show that the given equation has at least one solution in the indicated interval. Note that you are NOT asked to find the solution only show that at least one must exist in the indicated interval. \(25 - 8{x^2} - {x^3} = 0\) on \(\left[{ - 2,4} \right]\) Solution If perhaps you seek advice with algebra and in particular with Multi-step Equation Calculator Online or adding come pay a visit to us at Mathscitutor.com. We offer a great deal of really good reference information on topics starting from a quadratic to rationalizing 28.01.2018 · For problems 13 – 15 use the Intermediate Value Theorem to show that the given equation has at least one solution in the indicated interval. Note that you are NOT asked to find the solution only show that at least one must exist in the indicated interval. \(25 - 8{x^2} - {x^3} = 0\) on \(\left[{ - 2,4} \right]\) Solution