Reference Guide to Turbo Pascal Programs

ArFcnTab

Function Constructs a TABle of values of the six ARithmetic FunCtioNs $\omega(n) = \sum_{p|n} 1$, $\Omega(n) = \sum_{p^a\|n} a$, $\mu(n)$, $d(n) = \sum_{d|n} 1$, $\phi(n)$, and $\sigma(n) = \sum_{d|n} d$.

Syntax `arfcntab`

Commands

`PgUp`	Display the preceding 20 values
`PgDn`	Display the next 20 values
`J`	Jump to a new point in the table
`P`	Print 500 values, starting at the top of the displayed screen
`Esc`	Escape from the environment

Restrictions $1 \le n < 10^9$

Algorithm When the program begins execution, it first constructs a list of the primes not exceeding $10^{9/2}$, by sieving. These primes are used for trial division. The factorizations are determined simultaneously for all 20 numbers (or all 500 numbers, in the case of printing).

See also Pi

Car

Function Computes the CARmichael function $c(m)$, which is defined to be the least positive integer c such that $a^c \equiv 1 \pmod m$ whenever $(a, m) = 1$.

Syntax `car` [m]

Restrictions $1 \le m < 10^{18}$

Algorithm First the canonical factorization of m is determined by trial division. If p is an odd prime then $c(p^j) = p^{j-1}(p-1)$. Also, $c(2) = 1$, $c(4) = 2$, and $c(2^j) = 2^{j-2}$ for $j \ge 3$. Finally, $c(m)$ is the least common multiple of the numbers $c(p^\alpha)$ for $p^\alpha \| m$.

See also Phi

Comments This program provides a user interface for the function Carmichael found in the NoThy unit. To see how the algorithm is implemented, examine the file `nothy.pas`.

ClaNoTab

Function Constructs a TABle of CLAss Numbers of positive definite binary quadratic forms. The number $H(d)$ is the total number of equivalence classes of such forms of discriminant d, while $h(d)$ counts only those equivalence classes consisting of primitive forms.

Syntax `clanotab`

Commands

`PgUp`	Display the preceding 40 values
`PgDn`	Display the next 40 values
`J`	Jump to a new point in the table
`P`	Print $h(d)$ and $H(d)$ for $-2400 \le d < 0$
`Esc`	Escape from the environment

Restrictions $-10^4 \le d < 0$

Algorithm All reduced triples (a, b, c) are found, with $0 < a < \sqrt{10^4/3}$. When a reduced triple is located, the value $d = b^2 - 4ac$ is calculated, and the count of $H(d)$ is increased by 1. If $\gcd(a, b, c) = 1$ then the count of $h(d)$ is also increased by 1. The entire table is calculated before the first screen of values appears. This may take several minutes on a slow machine.

See also QFormTab, Reduce

Comments The time required to calculate class numbers in this manner in the range $-D \le d < 0$ is roughly proportional to $D^{3/2}$, and roughly D numbers must be stored. By adopting a more sophisticated algorithm, one could calculate only those values that are to appear on a given screenful, and the time required for the calculation would be much smaller, making it feasible to construct a program of this sort that would accommodate d in the range $-10^9 \le d < 0$, say. For faster algorithms, see D. Shanks, *Class number, a theory of factorization, and genera,* Proc. Sympos. Pure Math. **20**, Amer. Math. Soc. Providence, 1970, 415–440. For a method that is theoretically still faster, but that may be challenging to implement, see J. L. Hafner and K. S. McCurley, *A rigorous subexponential algorithm for computation of class groups*, J. Amer. Math. Soc. **2** (1989), 837–850.

CngArTab

Function Displays the addition and multiplication TABles for CoNGruence ARithmetic (mod m).

Syntax `cngartab`

Commands

$\uparrow$	Move up
$\downarrow$	Move down
$\leftarrow$	Move left
$\rightarrow$	Move right
`a`	Start at column a
`b`	Start at row b
`m`	Set modulus m
`s`	Switch between addition and multiplication
`r`	Display only reduced residues (in multiplication table)
`p`	Print the table (if $m \le 24$)
`Esc`	Escape from the environment

Restrictions $1 \le m < 10^9$

See also PowerTab

CRT

Function Determines the intersection of two arithmetic progressions. Let $g = (m_1, m_2)$. The set of x such that $x \equiv a_1 \pmod{m_1}$, $x \equiv a_2 \pmod{m_2}$ is empty if $a_1 \not\equiv a_2 \pmod{g}$. Otherwise the intersection is an arithmetic progression $a \pmod{m}$. In the Chinese Remainder Theorem it is required that $g = 1$, and then $m = m_1 m_2$. In general, $m = m_1 m_2 / g$.

Syntax `crt` [`a`$_1$ `m`$_1$ `a`$_2$ `m`$_2$]

Restrictions $|a_i| < 10^{18}$, $1 \le m_i < 10^{18}$

Algorithm First the linear congruence $m_1 y \equiv a_2 - a_1 \pmod{m_2}$ is solved. If $a_1 \not\equiv a_2 \pmod{g}$, then this congruence has no solution, and the intersection of the two given arithmetic progressions is empty. Otherwise, let y denote the unique solution of this congruence in the interval $0 \le y < m_2/g$. Then the intersection of the two given arithmetic progressions is the set of integers $x \equiv a \pmod{m}$ where $a = ym_1 + a_1$ and $m = m_1 m_2 / g$.

See also CRTDem, IntAPTab, LinCon, LnCnDem

Comments This program provides a user interface for the procedure CRThm found in the NoThy unit. To see how the algorithm is implemented, examine the file `nothy.pas`.

CRTDem

Function Demonstrates the method employed to determine the intersection of two given arithmetic progressions.

Syntax `crtdem` [$\mathtt{a_1\ m_1\ a_2\ m_2}$]

Restrictions $|a_i| < 10^{18}$, $1 \le m_i < 10^{18}$

Algorithm See the description given for the program CRT.

See also CRT, IntAPTab, LnCnDem

DetDem

Function Demonstrates the method used to evaluate $\det(A) \pmod{m}$.

Syntax `detdem`

Restrictions $0 < m < 10^9$, $A = [a_{ij}]$ is $n \times n$ with $1 \le n \le 9$, $|a_{ij}| < 10^9$

Algorithm See description for the program DetModM.

See also DetModM, SimLinDE

DetModM

Function Determines $\det(A) \pmod{m}$.

Syntax `detmodm`

Commands

`A`	Assign dimension of matrix
`B`	Build matrix
`C`	Choose modulus
`D`	Determine value of $\det(A) \pmod{m}$
`E`	Exit
`F`	Form altered matrix

Restrictions $0 < m < 10^9$, $A = [a_{ij}]$ is $n \times n$ with $1 \le n \le 9$, $|a_{ij}| < 10^9$

Algorithm Row operations are performed until the matrix is upper-triangular. After each row operation, the elements of the new matrix are reduced modulo m. The row operations used are of the following two types: (i) Exchange two rows (which multiplies the determinant by -1); (ii) Add an integral multiple of one row to a different row (which leaves the determinant unchanged).

See also DetDem, SimLinDE

Comments This program provides a user interface for the function DetModM, which is defined in the file det.i.

EuAlDem1

Function Demonstrates the calculation of (b, c) by using the identities $(b, c) = (-b, c)$, $(b, c) = (c, b)$, $(b, c) = (b + mc, c)$, $(b, 0) = |b|$.

Syntax `eualdem1`

Restrictions $|b| < 10^{18}$, $|c| < 10^{18}$

Algorithm The number m is chosen so that $b + mc$ lies between 0 and c. The systematic use of the Division Algorithm in this way is known as the *Euclidean Algorithm*.

See also EuAlDem2, EuAlDem3, FastGCD, GCD, GCDTab, LnComTab, SlowGCD

EuAlDem2

Function Demonstrates the extended EUclidean ALgorithm by exhibiting a table of the quotients q_i, remainders r_i, and the coefficients x_i, y_i in the relations $r_i = x_i b + y_i c$.

Syntax `eualdem2`

Commands

`PgUp`	Display the top portion of the table
`PgDn`	Display the bottom portion of the table
`b`	Enter a new value of b
`c`	Enter a new value of c
`P`	Print the table
`Esc`	Escape from the environment

Restrictions $0 < b < 10^{18}$, $0 < c < 10^{18}$

See also EuAlDem1, EuAlDem3, FastGCD, GCD, GCDTab, LnComTab, SlowGCD

EuAlDem3

Function Demonstrates the extended EUclidean ALgorithm in the same manner as EuAlDem2, but with rounding to the nearest integer instead of rounding down.

Syntax `eualdem3`

Commands

`PgUp`	Display the top portion of the table
`PgDn`	Display the bottom portion of the table
`b`	Enter a new value of b
`c`	Enter a new value of c
`P`	Print the table
`Esc`	Escape from the environment

Restrictions $0 < b < 10^{18}$, $0 < c < 10^{18}$

See also	EuAlDem1, EuAlDem2, FastGCD, GCD, GCDTab, LnComTab, SlowGCD

FacTab

Function	Constructs a TABle of the least prime FACtor of odd integers from $10N+1$ to $10N+199$.
Syntax	`factab`
Commands	

`PgUp`	Display the preceding 100 values (i.e. decrease N by 20)
`PgDn`	Display the next 100 values (i.e. increase N by 20)
`N`	New N; view table starting at $10N+1$
`Esc`	Escape from the environment

Restrictions	Integers not exceeding 10^9+189 (i.e. $0 \le N \le 99999999$).
Algorithm	When the program begins execution, it first constructs a list of the odd primes not exceeding $\sqrt{10^9+200}$, by sieving. We call these the "small primes." There are 15803 such primes, the last one being 31607. The next prime after this is 31621. When N is specified, the odd integers in the interval $[10N, 10N+200]$ are sieved by those small primes not exceeding $\sqrt{10N+200}$; least prime factors are noted as they are found.
See also	Factor, GetNextP

Factor

Function	FACTORs a given integer n.
Syntax	`factor` [`n`]
Restrictions	$\lvert n\rvert < 10^{18}$
Algorithm	Trial division. After powers of 2, 3, and 5 are removed, the trial divisors are reduced residues modulo 30.
See also	P-1, P-1Dem, Rho, RhoDem
Comments	Factors are reported as they are found. The program can be interrupted by touching a key. This program provides a user interface for the procedure Canonic found in the NoThy unit. To view the source code, examine the file `nothy.pas`.

FareyTab

Function	Constructs a TABle of FAREY fractions of order Q. Fractions are displayed in both rational and decimal form, up to 20 of them at a time.

Syntax	`fareytab`	
Commands	`PgUp`	View the next 19 smaller entries
	`PgDn`	View the next 19 larger entries
	`D`	Center the display at a decimal x
	`R`	Center the display at a rational number a/q
	`P`	Print the table (allowed for $Q \le 46$)
	`Esc`	Escape from the environment

Restrictions $1 \le Q < 10^9$

Algorithm If a/q and a'/q' are neighboring Farey fractions of some order Q, say $a/q < a'/q'$, then $a'q - q'a = 1$. By the extended Euclidean algorithm, for given relatively prime a and q we find x and y such that $xq - ya = 1$. Then $q' = y + kq$, $a' = x + ka$ where k is the largest integer such that $y + kq \le Q$. With a/q given, the next smaller Farey fraction a''/q'' is found similarly. The Farey fractions surrounding a given decimal number x are found by the continued fraction algorithm. Fractions are computed only as needed by the screen or the printer.

FastGCD

Function Times the execution of the Euclidean algorithm in calculating the Greatest Common Divisor of two given integers.

Syntax `fastgcd`

Restrictions $|b| < 10^{18}$, $|c| < 10^{18}$

Algorithm Euclidean algorithm, rounding down.

See also GCD, SlowGCD

FctrlTab

Function Provides a table of $n!$ (mod m). Each screen displays 100 values.

Syntax `fctrltab`

Commands	`PgUp`	View the preceding 100 entries
	`PgDn`	View the next 100 entries
	`J`	Jump to a new position in the table
	`M`	Enter a new modulus
	`P`	Print the first 60 lines of the table
	`Esc`	Escape from the environment

Restrictions $0 \le n \le 10089$, $0 < m < 10^6$

Algorithm All 10089 values are calculated as soon as m is specified, unless $m < 10089$, in which case only m values are calculated.

GCD

Function Calculates the Greatest Common Divisors of two given integers.

Syntax `gcd [b c]`

Restrictions $|b| < 10^{18}$, $|c| < 10^{18}$

Algorithm Euclidean algorithm with rounding to the nearest integer.

See also EuAlDem1, EuAlDem2, EuAlDem3, FastGCD, GCDTab, LnComTab, SlowGCD

Comments This program provides a user interface for the function of the same name in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

GCDTab

Function Displays (b, c) for pairs of integers.

Syntax `gcdtab`

Commands

$\uparrow$	Move up
$\downarrow$	Move down
$\leftarrow$	Move left
$\rightarrow$	Move right
`b`	Center table on column b
`c`	Center table on row c
`Esc`	Escape from the environment

Restrictions $|b| < 10^{18}$, $|c| < 10^{18}$

Algorithm Euclidean algorithm.

See also GCD, EuAlDem1, EuAlDem2, EuAlDem3, LnComTab

GetNextP

Function Finds the least Prime larger than a given integer x, if $x \leq 10^9$. If $10^9 < x < 10^{18}$, it finds an integer n, $n > x$, such that the interval (x, n) contains no prime but n is a strong probable prime to bases 2, 3, 5, 7, and 11. A rigorous proof of the primality of n can be obtained by using the program ProveP.

Syntax `getnextp` [x]

Restrictions $0 \le x < 10^{18}$

Algorithm If $0 \le x \le 10^9$ then the least prime larger than x is found by sieving. If $10^9 < x < 10^{18}$ then strong probable primality tests are performed.

See also FacTab, ProveP

Comments For $0 \le x \le 10^9$, this program provides a user interface for the function of the same name in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`. For $10^9 < x < 10^{18}$ this program uses the function SPsP, which is found in the unit NoThy, with source code in the file `nothy.pas`.

Hensel

Function Provides a table of solutions of $f(x) \equiv 0 \pmod{p^j}$, in the manner of HENSEL's lemma. All roots (mod p) are found, by trying every residue class. If $f(a) \equiv 0 \pmod{p}$ and $f'(a) \not\equiv 0 \pmod{p}$, then a tower of roots lying above a is displayed. If $f'(a) \equiv 0 \pmod{p}$ then roots lying above a are exhibited only one at a time. Roots (mod p^j) are displayed both in decimal notation and in base p, $a = \sum_{i \ge 1} c_i p^{i-1}$. The user must choose between viewing singular or non-singular roots. The display starts with a non-singular root, if there are any.

Syntax `hensel`

Commands

↑	Lift to larger values of j
↓	Drop to smaller values of j
←	Shift left in the table
→	Shift right in the table
`S`	Switch to singular roots
`N`	Switch to non-singular roots
`D`	Define the polynomial
`p`	Choose the prime modulus
`Esc`	Escape from the environment

Restrictions $2 \le p < 2000$, $p^j \le 10^{18}$, $f(x)$ must be the sum of at most 20 monomials

Algorithm The polynomial $f(x)$ is evaluated at every residue class, and an array is formed of the roots. For each root found, the quantity $f'(x)$ is calculated, in order to determine whether the root is singular or not.

See also PolySolv

HSortDem

Function DEMonstrates the HeapSORT algorithm of J. W. J. Williams, by applying the algorithm to n randomly chosen integers taken from the interval $[0, 99]$. This algorithm is employed in the programs Ind and IndDem.

Syntax `hsortdem`

Restrictions $1 \le n \le 31$

Ind

Function Given g, a, and p, finds the least non-negative ν such that $g^\nu \equiv a \pmod{p}$, if such a ν exists. Thus, if g is a primitive root of p, then $\nu = \operatorname{ind}_g a$.

Syntax `ind [g a p]`

Restrictions $|g| < 10^9$, $|a| < 10^9$, $1 < p < 10^9$, $(g, p) = 1$

Algorithm First LinCon is used to find $\overline{g} \pmod{p}$ so that $g\overline{g} \equiv 1 \pmod{p}$. The number s is taken to be either the integer nearest $\sqrt{p}$ or else 10000, which ever is smaller. A table is made of the residue classes $a\overline{g}^j \pmod{p}$ for $0 \le j < s$. This table is sorted by the HeapSort algorithm into increasing order. For $j = 0, 1, \ldots$, a search is conducted (by binary subdivisions) to see whether the residue class $g^{js} \pmod{p}$ is in the table. If a match is found, then $\nu = is + j$. If j reaches p/s without finding a match, then a is not a power of $g \pmod{p}$. Thus the index is found in time $O(p^{1/2} \log p)$. This method was suggested by D. Shanks.

See also IndDem, IndTab, Power, PowerTab

IndDem

Function DEMonstrates procedure used to compute $\operatorname{ind}_g a \pmod{p}$.

Syntax `inddem [g a p]`

Restrictions $|g| < 10^9$, $|a| < 10^9$, $1 < p < 10^9$

Algorithm See the description of the program Ind.

See also Ind, IndTab, Power, PowerTab

IndTab

Function Generates a TABle of INDices of reduced residue classes modulo a prime number p, with respect to a specified primitive root. Also generates a table of powers of the primitive root, modulo p. Up to 200 values are displayed a one time.

Syntax `indtab`

Commands

`PgUp`	View the preceding 200 entries
`PgDn`	View the next 200 entries
`J`	Jump to a new position in the table
`E`	Switch from indices to exponentials
`I`	Switch from exponentials to indices
`M`	Enter a new prime modulus
`B`	Choose a new primitive root to use as the base
`P`	Print table(s)
`Esc`	Escape from the environment

Restrictions $p < 10^4$

Algorithm The least positive primitive root g of p is found using the program PrimRoot. The powers of g modulo p and the indices with respect to g are generated in two arrays.

See also PowerTab, PrimRoot

IntAPTab

Function Creates a TABle with rows indexed by $a \pmod{m}$ and columns indexed by $b \pmod{n}$. The INTersection of these two Arithmetic Progressions is displayed (if it is nonempty) as a residue class (mod $[m, n]$).

Syntax `intaptab`

Commands

$\uparrow$	Move up
$\downarrow$	Move down
$\leftarrow$	Move left
$\rightarrow$	Move right
`a`	Start at row a
`b`	Sart at column b
`m`	Set modulus m
`n`	Set modulus n
`p`	Print (when table is small enough)
`Esc`	Escape from the environment

Restrictions $m < 10^4$, $n < 10^4$

Algorithm Chinese Remainder Theorem

See also CRT, CRTDem

Comments Reduced residues are written in white, the others in yellow.

Jacobi

Function Evaluates the JACOBI symbol $\left(\frac{P}{Q}\right)$.

Syntax `jacobi` [`P Q`]

Restrictions $|P| < 10^{18}$, $0 < Q < 10^{18}$

Algorithm Modified Euclidean algorithm, using quadra- tic reciprocity.

See also JacobDem, JacobTab

Comments This program provides a user interface for the function of the same name found in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

JacobDem

Function DEMonstrates the use of quadratic reciprocity to calculate the JACOBi symbol $\left(\frac{P}{Q}\right)$.

Syntax `jacobdem` [`P Q`]

Restrictions $|P| < 10^{18}$, $0 < Q < 10^{18}$

Algorithm Modified Euclidean algorithm, using quadratic reciprocity.

See also Jacobi, JacobTab

JacobTab

Function Generates a TABle of values of the JACOBi function, with 200 values displayed at one time.

Syntax `jacobtab`

Commands

`PgUp`	View the preceding 200 entries
`PgDn`	View the next 200 entries
`J`	Jump to a new position in the table
`Q`	Enter a new denominator Q
`P`	Print 500 lines, starting with the top line displayed
`Esc`	Escape from the environment

Restrictions $|P| < 10^{18}$, $0 < Q < 10^{18}$

Algorithm Values are calculated as needed, using the function Jacobi.

See also Jacobi, JacobDem

LinCon

Function Finds all solutions of the LINear CONgruence $ax \equiv b \pmod{m}$.

Syntax `lincon` [`a b m`]

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm The extended Euclidean algorithm is used to find both the number $g = (a, m)$ and a number u such that $au \equiv g \pmod{m}$. If $g \nmid b$ then there is no solution. Otherwise, the solutions are precisely those x such that $x \equiv c \pmod{m/g}$ where $c = ub/g$.

See also LnCnDem

Comments This program provides a user interface for a function of the same name in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

LnCnDem

Function DEMonstrates the method used to find all solutions to the LiNear CoNgruence $ax \equiv b \pmod{m}$.

Syntax `lncndem` [`a b m`]

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm See the description given for LinCon.

See also LinCon

LnComTab

Function Creates a TABle of the LiNear COMbinations $bx + cy$ of b and c, with columns indexed by x and rows indexed by y.

Syntax `lncomtab`

Commands

↑	Move up
↓	Move down
←	Move left
→	Move right
`x`	Left column is x
`y`	Bottom row is y
`b`	Set value of b
`c`	Set value of c
`Esc`	Escape from the environment

Restrictions $|b| < 10^9$, $|c| < 10^9$, $|x| < 10^9$, $|y| < 10^9$

See also GCD, GCDTab, EuAlDem1, EuAlDem2, EuAlDem3

Lucas

Function Calculates the LUCAS functions $U_n, V_n \pmod m$. Here the U_n are generated by the linear recurrence $U_{n+1} = aU_n + bU_{n-1}$ with the initial conditions $U_0 = 0$, $U_1 = 1$. The V_n satisfy the same linear recurrence, but with the initial conditions $V_0 = 2$, $V_1 = a$.

Syntax `lucas [n [a b] m]` If n, m are specified on the command line, but not a, b, then by default $a = b = 1$.

Restrictions $0 \le n < 10^{18}$, $|a| < 10^{18}$, $|b| \le 10^{18}$, $0 < m \le 10^{18}$

Algorithm To calculate $U_n \pmod m$, the pair of residue classes $U_{k-1}, U_k \pmod m$ is determined for a sequence of values of k, starting with $k = 1$. If this pair is known for a certain value of k, then it can be found with k replaced by $2k$, by means of the *duplication formulae*

$$\begin{aligned} U_{2k-1} &= U_k^2 + bU_{k-1}^2, \\ U_{2k} &= 2bU_{k-1}U_k + aU_k^2. \end{aligned}$$

This is called "doubling." Alternatively, the value of k can be increased by 1 by using the defining recurrence. This is called "sidestepping." By repeatedly doubling, with sidesteps interspersed as appropriate, eventually $k = n$.

To calculate $V_n \pmod m$, the pair V_k, V_{k+1} of residue classes (mod m) is determined for a sequence of values of k, starting with $k = 0$. The duplication formulae are now

$$\begin{aligned} V_{2k} &= V_k^2 - 2(-b)^k, \\ V_{2k+1} &= V_kV_{k+1} - a(-b)^k. \end{aligned}$$

Instead of sidestepping separately, an arithmetic economy is obtained by doubling with sidestep included by means of the formulae

$$\begin{aligned} V_{2k+1} &= V_kV_{k+1} - a(-b)^k, \\ V_{2k+2} &= V_{k+1}^2 - 2(-b)^{k+1}. \end{aligned}$$

By employing these transformations we eventually reach $k = n$.

The k that arise have binary expansions that form initial segments of the binary expansion of n, in the same manner as in the alternative powering algorithm discussed in the program PwrDem2.

The system of calculation here is superior to that found in the Fifth

Edition of NZM, where the sidestep formula involves division by 2 and is therefore appropriate only for odd moduli.

See also LucasDem, LucasTab, PwrDem2

Comments If $a = b = 1$ then U_n, V_n are the familiar Fibonacci and Lucas sequences F_n, L_n, respectively. This program provides a user interface for the functions LucasU and LucasV found in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

LucasDem

Function DEMonstrates the method used to calculate the LUCAS functions U_n, $V_n \pmod{m}$.

Syntax `lucasdem [n [a b] m]`

Restrictions $0 \le n < 10^{18}$, $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm See the description given for the program Lucas.

See also Lucas, LucasDem, PwrDem2

LucasTab

Function Generates a TABle of values of the LUCAS functions $U_n, V_n \pmod{m}$.

Syntax `lucastab`

Commands

`PgUp`	Display the preceding 100 values
`PgDn`	Display the next 100 values
`U`	Switch from V to U
`V`	Switch from U to V
`n`	Move to a screen with n on the top line
`a`	Choose a new value for the parameter a
`b`	Choose a new value for the parameter b
`M`	Choose a new modulus m
`P`	Print the initial 60 rows of the table ($0 \le n \le 599$)
`Esc`	Escape from the environment

Restrictions $0 \le n < 10^6$, $|a| < 10^6$, $|b| < 10^6$, $0 < m < 10^6$

See also Lucas, LucasDem

Mult

Function MULTiplies residue classes. If a, b, and m are given with $m > 0$, then c is found so that $c \equiv ab \pmod{m}$ and $0 \le c < m$.

Syntax `mult [a b m]`

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm If $m \le 10^9$ then ab is reduced modulo m. If $10^9 < m \le 10^{12}$ then we write $a = a_1 10^6 + a_0$, and compute $a_1 b 10^6 + a_0 b$ modulo m, with reductions modulo m after each multiplication. Thus all numbers encountered have absolute value at most 10^{18}. If $10^{12} < m < 10^{18}$ then we write $a = a_1 10^9 + a_0$, $b = b_1 10^9 + b_0$; we compute ab/m in floating-point real arithmetic and let q be the integer nearest this quantity; we write $q = q_1 10^9 + q_0$; $m = m_1 10^9 + m_0$. Then

$$ab - qm = ((a_1 b_1 - q_1 m_1)10^9 + a_1 b_0 + a_0 b_1 - q_1 m_0 - q_0 m_1)10^9 + a_0 b_0 - q_0 m_0.$$

The right hand side can be reliably evaluated, and this quantity has absolute value less than m. If it is negative we add m to it to obtain the final result. The assumption is that the machine will perform integer arithmetic accurately for integers up to $4 \cdot 10^{18}$ in size. The object is to perform congruence arithmetic with a modulus up to 10^{18} without introducing a full multiprecision package.

See also MultDem1, MultDem2, MultDem3

Comments This program provides a user interface for the function of the same name found in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

MultDem1

Function DEMonstrates the method employed by the program MULT when $10^9 < m < 10^{12}$.

Syntax `multdem1`

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm See Problem *21, Section 2.4, p. 83, of the Fifth Edition of NZM.

See also Mult, MultDem2, MultDem3

MultDem2

Function DEMonstrates the method used by the program MULT when $10^{12} < m < 10^{18}$.

Syntax `multdem2`

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm See the description given for the program Mult.

See also Mult, MultDem1, MultDem3

MultDem3

Function DEMonstrates the method used by the program MULT, in which the methods of MultDem1 and MultDem2 are merged.

Syntax `multdem3`

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $0 < m < 10^{18}$

Algorithm See the description given for the program Mult.

See also Mult, MultDem1, MultDem2

Order

Function Calculates the ORDER of a reduced residue class $a \pmod{m}$. That is, it finds the least positive integer h such that $a^h \equiv 1 \pmod{m}$.

Syntax `order` [`a m` [`c`]]

Restrictions $|a| < 10^{18}$, $0 < m < 10^{18}$, $0 < c < 10^{18}$

Algorithm The parameter c should be any known positive number such that $a^c \equiv 1 \pmod{m}$. For example, if m is prime then one may take $c = m - 1$. If a value of c is not provided by the user, or if the value provided is incorrect, then the program assigns $c = \text{Carmichael}(m)$. (This involves factoring m by trial division.) Once c is determined, then c is factored by trial division. Prime divisors of c are removed, one at a time, to locate the smallest divisor d of c for which $a^d \equiv 1 \pmod{m}$. This number is the order of a modulo m.

See also OrderDem

Comments This program provides a user interface for a function of the same name found in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

OrderDem

Function DEMonstrates the method used to calculate the order of a reduced residue class $a \pmod{m}$.

Syntax `order` [`a m` [`c`]]

Restrictions $|a| < 10^{18}$, $0 < m < 10^{18}$, $0 < c < 10^{18}$

Algorithm See the description given for the program Order.

See also Order

P–1

Function Factors a number n using the Pollard $p-1$ method.

Syntax `p-1` [`n` [`a`]] If n is specified on the command line, but not a, then by default $a = 2$.

Restrictions $1 < n < 10^{18}$, $1 < a < 10^{18}$

Algorithm The powering algorithm is used to calculate $a^{k!} \pmod{n}$ for increasingly large k, in the hope that a k will be found such that $1 < (a^{k!}-1, n) < n$. This method is generally fast for those n with a prime factor p such that $p-1$ is composed only of small primes.

See also P-1Dem, Rho, RhoDem, Factor

P–1Dem

Function Demonstrates the method used by the Pollard $p-1$ factoring scheme.

Syntax `p-1dem`

Restrictions $1 < n < 10^{18}$, $1 < a < 10^{18}$

Algorithm See the description given for the program P-1.

See also P-1

PascalsT

Function Constructs a table of PASCAL'S Triangle $\binom{n}{k} \pmod{m}$. Rows are indexed by n, columns by k. Up to 20 rows and 18 columns are displayed at one time.

Syntax `pascalst`

Commands

↑	Display the preceding 20 rows
↓	Display the next 20 rows
←	Display the preceding 20 columns
→	Display the next 20 columns
`T`	Move to the top of the triangle
`M`	Choose a new modulus
`Esc`	Escape from the environment

Restrictions $0 \le k \le n < 10^4$, $0 < m < 10^3$

Algorithm The rows are calculated inductively by the recurrence $\binom{n}{k-1} + \binom{n}{k} = \binom{n+1}{k}$. The entire nth row is calculated, where n is the top row on the current screen. Other entries in the screen are calculated from the top row.

Phi

Function Calculates the Euler PHI function of n.

Syntax `phi` [`n`]

Restrictions $1 \le n < 10^{18}$

Algorithm The canonical factorization of n is found by trial division, and then $\phi(n)$ is found by means of the formula $\phi(n) = \prod_{p^\alpha \| n} p^{\alpha-1}(p-1)$.

Comments This program provides a user interface for a function of the same name found in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

Pi

Function Determines the number $\pi(x)$ of primes not exceeding an integer x.

Syntax `pi` [`x`]

Restrictions $2 \le x 10^6$

Algorithm Primes up to 31607 are constructed, by sieving. These primes are used as trial divisors, to sieve intervals of length 10^4 until x is reached.

Comments This program would run perfectly well up to 10^9, but as the the running time is roughly linear in x, the smaller limit is imposed to avoid excessive running times. For faster methods of computing $\pi(x)$, see the following papers.
J. C. Lagarias, V. S. Miller, and A. M. Odlyzko, *Computing* $\pi(x)$: *The Meissel-Lehmer method*, Math. Comp. **44** (1985), 537–560.
J. C. Lagarias and A. M. Odlyzko, *New algorithms for computing* $\pi(x)$, Number Theory: New York 1982, D. V. Chudnovsky, G. V. Chudnovsky, H. Cohn and M. B. Nathanson, eds., Lecture Notes in Mathematics 1052, Springer-Verlag, Berlin, 1984, pp. 176–193.
J. C. Lagarias and A. M. Odlyzko, *Computing* $\pi(x)$: *an analytic method*, J. Algorithms **8** (1987), 173–191.

PolySolv

Function Finds all solutions of a given polynomial congruence $P(x) \equiv 0 \pmod{m}$.

Syntax `polysolv`

Commands

`C`	Count the zeros
`D`	Define the polynomial
`M`	Choose the modulus
`Esc`	Escape from the environment

Restrictions $1 \le m < 10^4$, $P(x)$ must be the sum of at most 20 monomials, only the first 100 zeros found are displayed on the screen

Algorithm The polynomial is evaluated at every residue class modulo m.

See also SqrtModP

Comments The running time here is roughly linear in m. When m is large there is a much faster way. By the Chinese Remainder Theorem it is enough to consider primepower values of m. By Hensel's lemma, this in turn can be reduced to the consideration of prime moduli. In the case of a prime modulus p, the roots of $P(x)$ modulo p can be found by calculating $(P(x), (x-a)^{(p-1)/2}-1)$ for various values of a. Here the gcd being calculated is that of two polynomials defined mod p. In the first step of the Euclidian algorithm, the remainder when $(x-a)^{(p-1)/2}-1$ is divided by $P(x)$ should be calculated by applying the powering algorithm to determine $(x-a)^{(p-1)/2} \pmod{\mathrm{d}\, p, P(x)}$. This approach extends to provide an efficient method of determining the factorization of $P(x) \pmod{p}$. For more information, see David G. Cantor and Hans Zassenhaus, *A new algorithm for factoring polynomials over finite fields*, Math. Comp. **36** (1981), 587–592.

Power

Function Computes $a^k \pmod{m}$ in the sense that it returns a number c such that $0 \le c < m$ and $c \equiv a^k \pmod{m}$.

Syntax `power [a k m]`

Restrictions $|a| < 10^{18}$, $0 \le k < 10^{18}$, $0 < m < 10^{18}$

Algorithm Write k in binary, say $k = \sum_{j \in \mathcal{J}} 2^j$. The numbers $a^{2^j} \pmod{m}$ are constructed by repeated squaring; whenever a $j \in \mathcal{J}$ is encountered, the existing product is multiplied by the factor a^{2^j}.

See also PowerTab, PwrDem1a, PwrDem1b, PwrDem2

Comments This program provides a user interface for a function of the same name in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

PowerTab

Function Constructs a TABle of POWERs $a^k \pmod{m}$. Up to 100 powers are displayed at a time.

Syntax `power`

Commands

`PgUp`	Display the preceding 10 rows
`PgDn`	Display the next 10 rows
`B`	Change the base
`E`	Move to a new exponent
`M`	Change the modulus
`P`	Print the first 60 lines of the table
`Esc`	Escape from the environment

Restrictions $|a| < 10^6$, $0 \le k < 10^6$, $0 < m < 10^6$

Algorithm The first entry on the screen is computed by the powering algorithm. Then the remaining entries on the screen are determined inductively.

See also CngArTab, Power, PwrDem1a, PwrDem1b, PwrDem2

PrimRoot

Function Finds the least primitive root g of a prime number p, such that $g > a$.

Syntax `primroot` [`p` [`a`]] If p is specified on the command line but not a, then by default $a = 0$.

Restrictions $2 \le p < 10^{18}$, $|a| < 10^{18}$

Algorithm The prime factors $q_1, q_2, \ldots, q_r$ of $p-1$ are found by trial division. Then g is a primitive root of p if and only if both $g^{p-1} \equiv 1 \pmod{p}$ and $g^{(p-1)/q_i} \not\equiv 1 \pmod{p}$ for all i, $1 \le i \le r$. When a g is found that satisfies these conditions, not only is g a primitive root of p, but also the primality of p is rigorously established. The algorithm employed by the program ProveP proceeds along these lines, but with some short cuts.

See also Order, OrderDem, ProveP

Comments This program provides a user interface for a function of the same name in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

ProveP

Function PROVEs that a given number p is Prime.

Syntax `provep [p]`

Restrictions $2 \le p < 10^{18}$

Algorithm Trial division is applied to $p-1$. Whenever a prime factor q of $p-1$ is found, say $q^k \| (p-1)$, attempts are made to find an a such that $a^{p-1} \equiv 1 \pmod{p}$ but $(a^{(p-1)/q}-1,\, p) = 1$. Suppose that such an a is found, and that $p'|p$. Let d denote the order of a modulo p'. Then $d|(p-1)$ but $d \nmid (p-1)/q$, and hence $q^k \| d$. But by Fermat's congruence $d|(p'-1)$, and hence it can be asserted that $q^k|(p'-1)$ for every prime factor p' of p. In other words, all prime factors p' of p are $\equiv 1 \pmod{q^k}$. If, for a given q, 200 unsuccessful attempts are made to find an admissible a, then presumably p is composite, and the program quits. Otherwise, the numbers q^k found are multiplied together to form a product s. Every prime factor p' of p is $\equiv 1 \pmod{s}$. If $s > \sqrt{p}$ then there can be at most one such prime, and the proof is complete. If $p^{1/3} < s \le p^{1/2}$ then there can be at most two such primes, say $p = p_1 p_2$. Write p_i in base s, $p_i = r_i s + 1$. Then $p = r_1 r_2 s^2 + (r_1 + r_2)s + 1$, and the coefficients of this polynomial in s can be found by expanding p in base s, say $p = c_2 s^2 + c_1 s + 1$. Then r_1 and r_2 are roots of the quadratic equation $(x - r_1)(x - r_2) = x^2 - c_1 x + c_2$, and hence the discriminant $c_1^2 - 4c_2$ must be a perfect square. In the unlikely event that this quantity is a perfect square, we are led to a factorization of p; otherwise we have a proof that p is prime.

If a point is reached at which it would take less time to test p for divisibility by numbers $d \equiv 1 \pmod{s}$, $d \le \sqrt{p}$ than has already been spent trying to factor $p-1$, then the program automatically switches to this latter approach.

The trial division of $p-1$ can be interrupted by touching a key, and the user can then supply a prime factor q of the remaining unfactored portion. The user is responsible for verifying that q is prime.

By this method we see that proving the primality of p is no harder than factoring $p-1$, and that for many p it is easier. Further methods of proving primality have been developed that are faster than the best known factoring methods. The mathematics exploited by these methods is much more sophisticated. For more precise information, consult the following papers.

A. O. L. Atkin and F. Morain, *Elliptic curves and primality proving*, Math. Comp. **61** (1993), 29–68 .

A. K. Lenstra and H. W. Lenstra, Jr., *Algorithms in number theory*, Handbook of Theoretical Computer Science, Vol. A, J. van Leeuwen, ed., Elsevier, Amsterdam, pp. 673–715.

PwrDem1a

Function DEMonstrates the powering algorithm.

Syntax `pwrdem1a` [`a k m`]

Restrictions $|a| < 10^{18}$, $0 \le k < 10^{18}$, $0 < m < 10^{18}$

Algorithm See the description given for the program Power.

See also Power, PwrDem1b, PwrDem2

PwrDem1b

Function An alternative DEMonstration of the powering algorithm.

Syntax `pwrdem1b` [`a k m`]

Restrictions $|a| < 10^{18}$, $0 \le k < 10^{18}$, $0 < m < 10^{18}$

Algorithm See the description given for the program Power.

See also Power, PwrDem1a, PwrDem2

PwrDem2

Function DEMonstrates an alternative powering algorithm.

Syntax `pwrdem2` [`a k m`]

Restrictions $|a| < 10^{18}$, $0 \le k < 10^{18}$, $0 < m < 10^{18}$

Algorithm A sequence of powers of a is generated, in which the binary expansions of the exponents form initial segments of the binary expansion of k. For example, if $k = 10111$ in binary, then (with all exponents written in binary) we start with a^1, square to form a^{10}, square again to form a^{100}, multiply by a to form a^{101}, square this to form a^{1010}, multiply by a to form a^{1011}, square this to form a^{10110}, and finally multiply by a to form a^{10111}. Of course all multiplications are carried out modulo m. In the original method used by the program Power, the binary expansions of the exponents form terminal segments of the binary expansion of k. The number of multiplications is exactly the same in the two methods, but this alternative method has an advantage in situations in which multiplication by a is fast for some reason. For example, in powering a matrix A, multiplication by A is fast if A is sparse. Similarly, in computing $P(x)^k$, multiplication by $P(x)$ is fast if $P(x)$ has few monomial terms. The repeated doubling from the top down seen here is also appropriate to the calculation of solutions of linear recurrences.

See also Power, PwrDem1a, PwrDem1b, LucasDem

QFormTab

Function Generates a TABle of all reduced binary Quadratic FORMs $f(x, y) = ax^2, bxy + cy^2$ of given discriminant. These forms are reduced only in the sense defined in §3.5 of NZM. Hence if $d > 0$ then the reduced forms are not necessarily inequivalent. For each form, the content (a, b, c) is calculated.

Syntax `qformtab`

Commands

`PgUp`	Display the preceding 20 rows
`PgDn`	Display the next 20 rows
`d`	Choose a new discriminant
`P`	Print the first 600 lines of the table
`Esc`	Escape from the environment

Restrictions $|d| < 10^6$, at most 5000 forms are displayed

Algorithm Detailed search for all triples satisfying the definition. Thus the running time is essentially linear in $|d|$. This program could run for $|d|$ up to 10^9, but the stricter limit is imposed to avoid excessive running times. For faster methods, see the discussion of the program ClaNoTab.

See also ClaNoTab, Reduce

Rat

Function Finds the RATional number a/q with least q such that the initial decimal digits of a/q coincide with those of a given real number x.

Syntax `rat` [x]

Restrictions $|a| \le 10^{18}$, $1 \le q \le 10^{18}$

Algorithm Suppose that k decimal digits of x are given after the decimal point. Put $\delta = 0.5 \cdot 10^{-k}$. We want to find a/q with q minimal such that $|x - a/q| \le \delta$. By the continued fraction algorithm the least i is found such that $|x - h_i/k_i| \le \delta$. Then the desired rational number is given by $a = ch_{i-1} + h_{i-2}$, $q = ck_{i-1} + k_{i-2}$ where c is the least positive integer such that a/q lies in the specified interval. Since this inequality holds when $c = a_i$, it suffices to search the interval $[1, a_i]$.

Reduce

Function REDUCEs a binary quadratic form $f(x, y) = ax^2+bxy+cy^2$. If the three coefficients are given on the command line, then a reduced form $g(x, y)$

is found, with g equivalent to f. The discriminant d of these forms is also reported. A proper representation of a by g is also noted, and then the program terminates. If the coefficients are not given on the command line, then an environment for manipulating forms is entered. When a form is being reduced in this environment, a chain of equivalences is displayed, along with the matrix M that gives the equivalence, and the operation S or T^m that was applied to derive the new form from that in the preceding row of the table. Here $S = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$ and $T = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}$. The user also has the option of applying the operations S, T, and T^{-1}, one at a time. The table will hold up to 500 forms.

In the case that $d > 0$, the form is reduced only to the extent that $|a| < b \le |a| < |a|$ or $0 \le b \le |a| = |c|$, and consequently two reduced forms may be equivalent.

Syntax `reduce` [`a b c`]

Restrictions $|a| < 10^{18}$, $|b| < 10^{18}$, $|c| < 10^{18}$

Commands

`PgUp`	Display the preceding 6 rows
`PgDn`	Display the next 6 rows
`a`	Enter a new coefficient a
`b`	Enter a new coefficient b
`c`	Enter a new coefficient c
`R`	Reduce the form at the bottom of the table
`S`	Apply the transformation S
`T`	Apply the transformation T
`I`	Apply the transformation T^{-1}
`M`	Toggle between displaying $M{:}g \to f$ and $M{:}f \to g$
`P`	Print the table
`Esc`	Escape from the environment

See also ClaNoTab, QFormTab

Rho

Function Factors a given composite integer n by using Pollard's RHO method. This program should only be applied to numbers that are already known to be composite; if it is applied to a prime number then it will run endlessly without reaching any conclusion. The program can be interrupted by touching any key on the keyboard.

Syntax `rho` [`n` [`c`]] If n is specified on the command line but not c, then $c = 1$ by default.

Restrictions $1 < n < 10^{18}$, $|c| < 10^{18}$

Algorithm Let $u_0 = 0$, and for $i \geq 0$ let $u_{i+1} = u_i^2 + c$. The u_i are calculated modulo n, and for each i the quantity $(u_{2i} - u_i, n)$ is determined, in the hope of finding a proper divisor of n. The numbers u_i are not stored: At any one time only u_i and u_{2i} are known. If a proper divisor is found, it is not necessarily prime, and if it is prime it is not necessarily the least prime divisor of n. Various values of c may be used, but $c = 0$ and $c = -2$ should be avoided.

See also RhoDem, P-1, P-1Dem, Factor

RhoDem

Function DEMonstrates the Pollard RHO factoring scheme.

Syntax `rhodem` [`n`]

Restrictions $1 < n < 10^{18}$, $|c| < 10^{18}$

Algorithm See description given for the program Rho.

See also Rho, P-1, P-1Dem, Fac

RSA

Function Provides an environment for encrypting messages by means of the RSA method. The encrypting history is displayed.

Syntax `rsa`

Commands

`B`	Set the size of the blocks
`E`	Encode
`P`	Print the data
`R`	Enter a message as a sequence of residue classes
`T`	Enter a message in text form
`V`	Choose variables: modulus m, exponent k, etc.
`Esc`	Escape from the environment

Restrictions The block size must lie between 1 and 17, the text must consist of at most 80 characters, $0 < k < m < 10^{18}$

Algorithm Each residue class $a \pmod{m}$ is replaced by $b \equiv a^k \pmod{m}$. To decode, replace b by $b^{k'} \pmod{m}$ where $0 < k' < m$ and $kk' \equiv 1 \pmod{\phi(m)}$.

SimLinDE

Function Gives a complete parametric representation of the solutions to a system of SIMultaneous LINear Diophantine Equations $A\mathbf{x} = \mathbf{b}$. The user may request that the calculations be displayed.

Syntax `simlinde`

Restrictions A is $m \times n$ where $1 \le m \le 10$, $1 \le n \le 10$, all numbers occurring must have absolute value not exceeding 10^{18}

Algorithm Row operations and changes of variable are performed until the system is in diagonal form. The full Smith normal form is not reached. This method is prone to overflow. The program as written makes no special effort to avoid overflow, but reports when it has occurred.

SlowGCD

Function Times the calculation of the greatest common divisor of two numbers b and c, when only the definition is used. The only purpose in this is to provide a comparison with FastGCD.

Syntax `slowgcd`

Restrictions $1 \le b < 10^9$, $1 \le c < 10^9$

Algorithm For each d, $1 \le d \le \min(|b|, |c|)$, trial divisions are made to determine whether $d|b$ and $d|c$. A record is kept of the largest such d found. Since the running time is essentially linear in $\min(|b|, |c|)$, only small arguments should be used.

See also FastGCD, GCD

SPsP

Function Executes the Strong PseudoPrime test base a to the number m. This provides a rigorous proof of compositeness. If m survives such a test then it is not necessarily prime, but it is called a "probable prime" because pseudoprimes (i.e., composite probable primes) seem to form a sparse set.

Syntax `spsp [[a] m]` If m is specified on the command line, but not a, then by default $a = 2$.

Restrictions $|a| < 10^{18}$, $2 < m < 10^{18}$

Algorithm The strong pseudoprime test, as invented by John Selfridge and others. For a full description see NZM, p. 78.

See also SPsPDem, ProveP

SPsPDem

Function DEMonstrates the Strong PSeudoPrime test.

Syntax `spsp` [[`a`] `m`] If m is specified on the command line, but not a, then by default $a = 2$.

Restrictions $|a| < 10^{18}$, $2 < m < 10^{18}$

See also SPsP, ProveP

SqrtDem

Function DEMonstrates the calculation executed by the program SqrtModP.

Syntax `sqrtdem` [`a p`]

Restrictions $|a| < 10^{18}$, $2 \le p < 10^{18}$

Algorithm See the description given for the program SqrtModP

See also SqrtModP

SqrtModP

Function Calculates the SQuareRooT Modulo a given Prime number p. If the congruence $x^2 \equiv a \pmod p$ has a solution, then the unique solution x such that $0 \le x \le p/2$ is returned.

Syntax `sqrtmodp` [`a p`]

Restrictions $|a| \le 10^{18}$, $2 \le p \le 10^{18}$

Algorithm Uses the RESSOL algorithm of Dan Shanks. This is described in §2.9 of NZM. A different method, which depends on properties of the Lucas sequences, has been given by D. H. Lehmer, *Computer technology applied to the theory of numbers*, Studies in Number Theory, W. J. LeVeque, ed., Math. Assoc. Amer., Washington, 1969, pp. 117–151.

See also SqrtDem

Comments This program provides a user interface for a function of the same name in the unit NoThy. To see how the algorithm is implemented, inspect the file `nothy.pas`.

SumsPwrs

Function Finds all representations of n as a sum of s k-th powers, and counts them in various ways.

Syntax `sumspwrs [n s k]`

Restrictions $1 \le n < 10^{11}$, $2 \le s \le 75$, $2 \le k \le 10$

Algorithm After $s-1$ summands have been chosen, a test is made as to whether the remainder is a k-th power. Summands are kept in monotonic order; the multiplicity is recovered by computing the appropriate multinomial coefficient. In some cases, such as sums of two squares, much faster methods exist for finding all representations.

See also Wrg1Tab, Wrg2Tab, WrgStTab, WrgCnTab

Wrg1Tab

Function Creates a TABle of the number $r(n)$ of representations of $n = \sum_{i=1}^{s} x_i^s$ as a sum of s k-th powers, as in WARing's problem. If $k > 2$ then the x_i are non-negative, but for $k = 2$ the x_i are arbitrary integers.

Syntax `wrg1tab`

Commands

`PgUp`	Move up
`PgDn`	Move down
`s`	Set s, the number of summands
`k`	Set k, the exponent
`N`	Start the table at $10n$
`p`	Print the table
`Esc`	Escape from the environment

Restrictions $1 \le s \le 75$, $2 \le k \le 10$, $1 \le n \le 10^{11}$

Algorithm Search for representations, with summands in monotonic order. The multiplicity of a representation is recovered by multiplying by the appropriate multinomial coefficient.

See also SumsPwrs, Wrg2Tab, WrgStTab, WrgCnTab

Wrg2Tab

Function Creates a TABle of the least number s of k-th powers required to represent n, in connection with WARing's problem.

Syntax `wrg2tab`

Commands

`PgUp`	Move up
`PgDn`	Move down
`k`	Set k, the exponent
`N`	Start the table at $10n$
`p`	Print the table
`Esc`	Escape from the environment

Restrictions $2 \le k \le 10$, $1 \le n \le 10^4$

Algorithm For $s \le k$, the numbers represented are found by allowing a k-tuple of variables run over all possible values, with coordinates in monotonic order. For $s > k$, all possible k-th powers are added to numbers already represented, until more than half the numbers have been represented. Then all possible k-th powers are subtracted from numbers not represented.

See also SumsPwrs, Wrg1Tab, Wrg2Tab, WrgCnTab

WrgCnTab

Function Creates a TABle of the number of solutions of the congruence $\sum_{i=1}^{s} x_i^k \equiv n \pmod{m}$, in connection with WARing's problem.

Syntax `wrgcntab`

Commands

`PgUp`	Move up
`PgDn`	Move down
`n`	First line displayed is n
`m`	Set the modulus m
`p`	Print the table
`Esc`	Escape from the environment

Restrictions $1 \le s \le 75$, $2 \le k \le 10$, $1 \le m < 5000$

Algorithm First a list of all k-th power residues r is constructed, with the number of solutions of $x^k \equiv r \pmod{m}$ is recorded. Summands run over monotonically ordered residues. To recover the multiplicity of a representation, one must multiply by the appropriate multinomial coefficient and by the multiplicities of the summands.

See also SumsPwrs, Wrg1Tab, Wrg2Tab, WrgStTab

Turbo Pascal Programming Resources

A collection of basic routines are provided for use in more advanced programs. These routines are accessed in one of two ways. First, there are files with the extension `.i` that may be *included* in another program. For example, to measure the running time of a program you may type `{$I timer.i }`. (The space after the `.i` is essential here.) The effect will be the same as if the text of the file timer.i had been pasted into your program at this point. Second, a library of 17 number-theoretic routines is provided in the Turbo Pascal unit nothy.tpu. This is a compiled module that the compiler will use when your program is compiled. The source code for this unit is in the file nothy.pas. To invoke this unit, the initial lines of your program should include commands of the following sort:

```
program TwoSquares;                {Use the method of Problem 6 on p. 333 to
                                    write a prime p as a sum of two squares}
{$N+,E+}
uses nothy;
```

Most of the routines in NoThy accept integers as variables of type comp, with a size up to 10^{18}. This type is available only after the compiler directive `{$N+}` has been given. Such variables are calculated on the arithmetic coprocessor, in floating point. If no coprocessor is found, then the program will crash, unless the compiler directive `{$E+}` has also been given, in which case the numerical work of the coprocessor will be emulated in software.

Canonic procedure — NoThy

Function Calculates the canonical factorization of an integer.

Declaration `canonic(n: comp; var k: integer; var p: primes; var m: multiplicity; var Prog: Boolean)`

Remarks This procedure uses two variable types defined within the NoThy unit: primes = array[1..15] of comp; multiplicity = array[1..15] of integer. k is the number of distinct primes dividing n; these primes are stored, in increasing order, in the array p. The multiplicity to which these primes divide n is recorded in the corresponding location in the array m. If Prog

= True then the progress in computing the factorization is reported to the screen. Since the underlying method is trial division, performance will be slow whenever n has a very large prime factor. In such a case, execution may be interrupted by typing any key.

Restrictions $1 \le n \le 10^{18}$

Carmichael function **NoThy**

Function Computes the Carmichael function of n. That is, the least positive integer c such that $a^c \equiv 1 \pmod{n}$ whenever $(a, n) = 1$.

Declaration `carmichael(n: comp)`

Result type comp

Remarks Since n is factored by trial division, performance will be slow if n has a very large prime factor. In such a case, the execution may be interrupted by typing any key.

Restrictions $1 \le n \le 10^{18}$

See also Phi

Condition function **NoThy**

Function Given a and m, the number b is returned where $b \equiv a \pmod{m}$ and $0 \le b < m$.

Declaration `condition(a, m: comp)`

Result type comp

Restrictions $|a| \le 10^{18}$, $1 \le m \le 10^{18}$

CRThm procedure **NoThy**

Function Determines the intersection of two given arithmetic progressions.

Declaration `CRThm(a1, m1, a2, m2: comp; var a, m: comp)`

Remarks If the intersection is empty then the value $m = 0$ is returned.

Restrictions $|a_i| \le 10^{18}$, $1 \le m_i \le 10^{18}$

DetModM function **det.i**

Function Calculates the determinant of an $n \times n$ integral matrix $A = [a_{ij}]$ modulo m.

Declaration `det(A: matrix; n: integer; m: comp)`

Result type comp

Remarks Before this function is called, the following variable type must be defined: matrix = array[1..9] of array[1..9] of comp.

Restrictions $|a_{ij}| \le 10^{18}$, $1 \le n \le 9$, $1 \le m \le 10^{18}$

GCD function NoThy

Function Calculates the greatest common divisor of two given integers b and c.

Declaration `gcd(b, c: comp)`

Result type comp

Remarks The gcd is undefined when $b = c = 0$.

Restrictions $|b| \le 10^{18}$, $|c| \le 10^{18}$

GetInput function GetInput.i

Function Moves the cursor to a specified location (x, y), and prompts the user for an integral input. On the line just below, a comment is provided, which typically concerns the range in which the input must lie. The input is accepted only when it lies in a specified interval $[a, b]$.

Declaration `getinput(x, y: integer; prompt, comm : string; a, b : comp)`

Result type comp

Remarks This function may be modified for more specialized tasks, as is the case with the function GetDisc found in the program QFormTab. Any program using this function must declare the unit CRT in the uses statement.

Restrictions $1 \le x \le 80$, $1 \le y \le 25$, $|a| \le 10^{18}$, $|b| \le 10^{18}$

Examples See the files factor.pas, phi.pas.

GetNextP function NoThy

Function Given an integer x, finds the least prime p such that $p > x$.

Declaration `getnextp(x: longint)`

Result type longint

Remarks If $x < 0$ or $x > 10^9$ then the value 0 is returned.

Restrictions $1 \le x \le 10^9$

Jacobi function **NoThy**

Function Calculates the Jacobi symbol $\left(\frac{P}{Q}\right)$.

Declaration `jacobi(p, q: comp)`

Result type integer

Restrictions $|P| \le 10^{18}$, $1 \le Q \le 10^{18}$, Q odd.

LinCon procedure **NoThy**

Function Solves the linear congruence $a_1 x \equiv a_0 \pmod{m}$. If solutions exist then they form an arithmetic progression, $x \equiv a \pmod{m_1}$.

Declaration `lincon(a1, a0, m: comp; var a, m1: comp)`

Remarks If $(a_1, m) \nmid a_0$ then the congruence has no solution, and the values $a = (a_1, m)$, $m_1 = 0$ are returned.

Restrictions $|a_i| \le 10^{18}$, $1 \le m \le 10^{18}$

LucasU function **NoThy**

Function Computes $U_n \pmod{m}$. Here U_n is the Lucas sequence with parameters a and b, defined by the recurrence $U_{n+1} = aU_n + bU_{n-1}$, with initial conditions $U_0 = 0$, $U_1 = 1$. If $a = b = 1$ then these are the Fibonacci numbers F_n.

Declaration `lucasu(n, a, b, m: comp)`

Result type comp

Restrictions $0 \le n \le 10^{18}$, $|a| \le 10^{18}$, $|b| \le 10^{18}$, $1 \le m \le 10^{18}$

See also LucasV

LucasV function **NoThy**

Function Computes $V_n \pmod{m}$. Here V_n is the Lucas sequence with parameters a and b, defined by the recurrence $V_{n+1} = aV_n + bV_{n-1}$, with initial conditions $V_0 = 0$, $V_1 = 1$. If $a = b = 1$ then these are the Lucas numbers L_n.

Declaration `lucasv(n, a, b, m: comp)`

Result type comp

Restrictions $0 \le n \le 10^{18}$, $|a| \le 10^{18}$, $|b| \le 10^{18}$, $1 \le m \le 10^{18}$

See also LucasU

Mult function NoThy

Function Given a, b, and m, returns the number c such that $c \equiv ab \pmod{m}$ and $0 \le c < m$.

Declaration `mult(a, b, m: comp)`

Result type comp

Remarks This allows congruence arithmetic for m up to 10^{18} without need for multiple precision arithmetic.

Restrictions $|a| \le 10^{18}$, $|b| \le 10^{18}$, $1 \le m \le 10^{18}$

Order function NoThy

Function Given a, m, and c such that $a^c \equiv 1 \pmod{m}$, the least positive integer h such that $a^h \equiv 1 \pmod{m}$ is returned.

Declaration `order(a, m, c: comp)`

Result type comp

Remarks If $(a, m) > 1$ then the value 0 is returned. If $(a, m) = 1$ but $a^c \not\equiv 1 \pmod{m}$ then an error message is printed and the program halts. Since c is factored by trial division, performance will be slow if c has a very large prime factor. In such a case, execution may be interrupted by typing any key.

Restrictions $|a| \le 10^{18}$, $1 \le m \le 10^{18}$, $1 \le c \le 10^{18}$

See also PrimRoot

Phi function NoThy

Function Computes the Euler phi function $\phi(n)$.

Declaration `phi(n: comp)`

Result type comp

Remarks Since n is factored by trial division, performance will be slow if n has a very large prime factor. In such a case, execution may be interrupted by typing any key.

Restrictions $1 \le n \le 10^{18}$

See also Carmichael

Power function — NoThy

Function Given a, k, and m, returns c such that $c \equiv a^k \pmod{m}$ and $0 \le c < m$.

Declaration `power(a, k, m: comp)`

Result type comp

Restrictions $|a| \le 10^{18}$, $0 \le k \le 10^{18}$, $1 \le m \le 10^{18}$

PrimRoot function — NoThy

Function Given an integer a and a prime number p, returns the least primitive root g of p such that $g > a$.

Declaration `primroot(p, a:  comp)`

Result type comp

Remarks Since $p - 1$ is factored by trial division, performance will be slow if $p - 1$ has a very large prime factor. In such a case, execution may be interrupted by typing any key.

Restrictions $|a| \le 10^{18}$, $2 \le p < 10^{18}$

ReadTimer procedure — Timer.i

Function Give the elapsed time since the timer was set.

Declaration `readtimer`

Remarks The elapsed time is stored in the variable TimerString, which is defined to be of type string[35]. The timer must be set before it can be read, by using the procedure SetTimer. Any program employing the timer must declare the unit DOS in the uses statement.

Restrictions The TimerString records only hours, minutes and seconds. If a program runs for more than 24 hours, the number of days must be added to the stated time.

See also SetTimer

Examples See the files slowgcd.pas, factor.pas.

SetTimer procedure — Timer.i

Function Sets the timer.

Declaration `settimer`

See also ReadTimer

SPsP function — NoThy

Function Applies the strong pseudoprime test base a to m.

Declaration `spsp(a, m: comp)`

Result type Boolean

Remarks If m is proved to be composite then the value False is returned; otherwise the calculation is consistent with the hypothesis that m is prime, and the value True is returned.

Restrictions $|a| \le 10^{18}$, $2 \le m \le 10^{18}$

SqrtModP function — NoThy

Function Given an integer a and a prime number p, returns the number x such that $x^2 \equiv a \pmod{p}$, $0 \le x \le p/2$.

Declaration `sqrtmodp(a, p: comp)`

Result type comp

Remarks If p is found to be composite, or if a is a quadratic nonresidue of p, then an error message is printed and the program halts.

Restrictions $|a| \le 10^{18}$, $2 \le p \le 10^{18}$