⍝ The Co-dfns Compiler

⍝ High-performance, Parallel APL Compiler

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:Namespace CODFNS

```
      ⎕IO ⎕ML ⎕WX    ← 0 1 3
          VERSION    ← 2017 12 2
       AF∆PREFIX     ← '/usr/local'
           AF∆LIB    ← ''
            VS∆PS    ← '\2017\'∘,¨ 'Enterprise' 'Professional' 'Community' ,¨ ⊂'\VC\Auxiliary\Build'
            VS∆PS   ,← ⊂' 14.0\VC'
            VS∆PS ,⍨¨← ⊂'\Program Files (x86)\Microsoft Visual Studio'
            VS∆PS  ,¨← ⊂'\vcvarsall.bat'

      Cmp ← {_ ← 1 ⎕NDELETE α, soext ⍬
             _ ← (⍸ opsys 'vsc' 'gcc' 'clang') α ⊣ (α, '.cpp') put⍨¨ gc tt ⊃ a n ← ps ω
             _ ← ⎕NEXISTS α, soext ⍬ ⋄ _ : n
                 'COMPILE ERROR' ⎕SIGNAL 22}
    MkNS ← {NS ⊣ α∘{NS.⍎α mkf ω}¨ (1 = 1 ⌷ ⍉⍵)⌿ 0 ⌷ ⍉ω ⊣ NS ← #.⎕NS ⍬}
     Fix ← {α MkNS α Cmp ω}
     Xml ← {⎕XML (0 ⌷ ⍉ω), (,∘⍪≠ 2 ↑ 1 ↓ ⍉ω), (⊂''), ⍪(⊂(¯3 + ≢⍉ω) ↑ ,¨ 'nrsgvyel') ,∘⍪¨ ↓ ⍪∘,¨ ⍉ 3 ↓ ⍉ω}
     MKA ← {mka ⊂ ω ⊣ 'mka' ⎕NA 'P  ', (α, soext ⍬), '|mkarray <PP'}
     EXA ← {exa ⍬ ω ⊣ 'exa' ⎕NA (α, soext ⍬), '|exarray >PP P'}
    FREA ← {frea ω ⊣ 'frea' ⎕NA (α, soext ⍬), '|frea P'}

  opsys ← {ω ⊃⍨ 'Win' 'Lin' 'Mac'⍳ ⊂ 3 ↑ ⊃ '.' ⎕WG 'APLVersion'}
  soext ← {opsys '.dll' '.so' '.dylib'}
    tie ← {0 :: ⎕SIGNAL ⎕EN ⋄ 22 :: ω ⎕NCREATE 0 ⋄ 0 ⎕NRESIZE ω ⎕NTIE 0}
    put ← {s ← (¯128 + 256 | 128 + 'UTF-8' ⎕UCS α) ⎕NAPPEND (t ← tie ω) 83 ⋄ 1 : r ← s ⊣ ⎕NUNTIE t}
    mkf ← {fn  ← (α, soext ⍬), '|', ('∆' ⎕R '__' ⊢ ω), '_dwa '
           f   ← ω, '←{_←''dya''⎕NA''', fn, '>PP <PP <PP'' ⋄ '
           f  ,← '_←''mon''⎕NA''', fn, '>PP P <PP'' ⋄ '
                f, '0=⎕NC''α'':mon 0 0 ⍵ ⋄ dya 0 α ⍵} ⋄ 0'}
```

```
   ccf ← {' -o ''', ⍵, '.', ⍺, ''' '''', ⍵, '.cpp'' -laf', AF∆LIB, ' > ', ⍵, '.log 2>&1'}
   cci ← {'-I''', AF∆PREFIX, '/include'' -L''', AF∆PREFIX, '/lib'' '}
   cco ← '-std=c++11 -Ofast -g -Wall -fPIC -shared'
   ucc ← {⍵⍵ (⎕SH ⍺⍺, '  ', cco, cci, ccf) ⍵}
   gcc ← 'g++' ucc 'so'
 clang ← 'clang++' ucc 'dylib'
  vsco ← {z ← '/W3 /wd4102 /wd4275 /Gm- /O2 /Zc:inline /Zi /Fd"', ⍵, '.pdb" '
          z ,← '/errorReport:prompt /WX- /MD /EHsc /nologo '
               z, '/I"%AF_PATH%\include" /D "NOMINMAX" /D "AF_DEBUG" '}
  vslo ← {z ← '/link /DLL /OPT:REF /INCREMENTAL:NO /SUBSYSTEM:WINDOWS '
          z ,← '/LIBPATH:"%AF_PATH%\lib" /DYNAMICBASE "af', AF∆LIB, '.lib" '
               z, '/OPT:ICF /ERRORREPORT:PROMPT /TLBID:1 '}
 vsc₀ ← {~∨≠ b ← ⎕NEXISTS¨ VS∆PS : 'MISSING VISUAL C++' ⎕SIGNAL 99 ⋄ '""', '" amd64' ,⍨ ⊃ b ≠ VS∆PS}
 vsc₁ ← {' && cd "', (⊃ ⎕CMD 'echo %CD%'), '" && cl ', (vsco ⍵), '/fast "', ⍵, '.cpp" '}
 vsc₂ ← {(vslo ⍵), '/OUT:"', ⍵, '.dll" > "', ⍵, '.log""'}
  vsc ← {⎕CMD ('%comspec% /C ', vsc₀, vsc₁, vsc₂) ⍵}

  get ← {⍺⍺ ⌷ ⍵⍵ ⍵}
 wrap ← ⍨∘(⍵⍵ (1 + 1 ↑ ⍵⍵) ⍨ 1 ↓ ⍵⍵)
 bind ← {n _ e ← ⍵ ⋄ (0 n_ ⌷ e) ← ⊂n ⋄ e}
   at ← {⍺ ← ⊢ ⋄ A ⊣ ((,B) ≠ (r A) ⍴ A) ← ⍺ ⍺⍺ (,B) ≠ ((r ← (≢⍴ B ← ⍵⍵ ⍵) ((×/ ↑) , ↓) ⍴) A) ⍴ (A ← ⍵)}

d_ t_ k_ n_ r_ s_ g_ v_ y_ e_ l_ ← ⍳ 7 + f∆ ← 4
d ← d_ get ⋄ t ← t_ get ⋄ k ← k_ get ⋄ n ← n_ get ⋄ r ← r_ get ⋄ s ← s_ get
g ← g_ get ⋄ v ← v_ get ⋄ y ← y_ get ⋄ e ← e_ get ⋄ l ← l_ get

 new ← {⍵⍵⍨ f∆ ↑ 0 ⍺, ⍵}                                  ⋄ msk ← {(t ⍵) ∈ ⊂⍺⍺} ⋄ sel ← {(⍺⍺ msk ⍵)≠ ⍵}
   A ← {('A' new ⍺⍺) wrap ⊃⍨/ ⍵}                          ⋄ A_m ← 'A' msk      ⋄ A_s ← 'A' sel
   E ← {('E' new ⍺⍺) wrap ⊃⍨/ ⍵}                          ⋄ E_m ← 'E' msk      ⋄ E_s ← 'E' sel
   F ← {('F' new ⍺⍺) wrap ⊃⍨/ (⊂ 0 f∆ ⍴ ⊖), ⍵}            ⋄ F_m ← 'F' msk      ⋄ F_s ← 'F' sel
   G ← {('G' new 0) wrap ⊃⍨/ ⍵}                           ⋄ G_m ← 'G' msk      ⋄ G_s ← 'G' sel
   L ← {('L' new 0) wrap ⊃⍨/ ⍵}                           ⋄ L_m ← 'L' msk      ⋄ L_s ← 'L' sel
   M ← {('M' new 0 '') wrap ⊃⍨/ (⊂ 0 f∆ ⍴ ⊖), ⍵}          ⋄ M_m ← 'M' msk      ⋄ M_s ← 'M' sel
   N ← {'N' new 0 (⍎⍵)}                                   ⋄ N_m ← 'N' msk      ⋄ N_s ← 'N' sel
   O ← {('O' new ⍺⍺) wrap ⊃⍨/ ⍵}                          ⋄ O_m ← 'O' msk      ⋄ O_s ← 'O' sel
   P ← {'P' new 0 ⍵}                                      ⋄ P_m ← 'P' msk      ⋄ P_s ← 'P' sel
   S ← {'S' new 0 ⍵}                                      ⋄ S_m ← 'S' msk      ⋄ S_s ← 'S' sel
   V ← {'V' new ⍺⍺ ⍵}                                     ⋄ V_m ← 'V' msk      ⋄ V_s ← 'V' sel
   Y ← {'Y' new 0 ⍵}                                      ⋄ Y_m ← 'Y' msk      ⋄ Y_s ← 'Y' sel
   Z ← {'Z' new 1 ⍵}                                      ⋄ Z_m ← 'Z' msk      ⋄ Z_s ← 'Z' sel
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      _o ← {0 ≥ ⊃ c a e r ← p ← α αα ω : p ⋄ 0 ≥ ⊃ c a e r₂ ← p ← α ωω ω : p ⋄ c a e (r ↑⍨ - ⌊/ ≢¨ r r₂)}
      _s ← {0 < ⊃ c a e r ← p ← α αα ω : p ⋄ 0 < ⊃ c₂ a₂ e r ← p ← e ωω r : p ⋄ (c ⌈ c₂)(a, a₂) e r}
  _noenv ← {0 < ⊃ c a e r ← p ← α αα ω : p ⋄ c a α r}
    _env ← {0 < ⊃ c a e r ← p ← α αα ω : p ⋄ c a (e ωω a) r}
   _then ← {0 < ⊃ c a e r ← p ← α αα ω : p ⋄ 0 < ⊃ c a e _ ← p ← e (ωω _s eot) a : p ⋄ c a e r}
    _not ← {0 < ⊃ c a e r ← α αα ω : 0 a α ω ⋄ 2 a α ω}
     _as ← {0 < ⊃ c a e r ← α αα ω : c a e r ⋄ c (,⊂ωω a) e r}
      _t ← {0 < ⊃ c a e r ← α αα ω : c a e r ⋄ e ωω a : c a e r ⋄ 2 ϴ α ω}
    _ign ← {c a e r ← α αα ω ⋄ c ϴ e r}
   _peek ← {0 < p ← ⊃ α αα ω : p ⋄ 0 ϴ α ω}
    _yes ← {0 ϴ α ω}
    _opt ← {α (αα _o _yes) ω}
    _any ← {α (αα _s ∇ _o _yes) ω}
   _some ← {α (αα _s (αα _any)) ω}
    _set ← {(0 ≠ ≢ω) ∧ (⊃ω) ∈ αα : 0 (,⊃ω) α (1 ↓ ω) ⋄ 2 ϴ α ω}
     _tk ← {((≢,αα) ↑ ω) ≡,αα : 0 (⊂,αα) α ((≢,αα) ↓ ω) ⋄ 2 ϴ α ω}
    _eat ← {0 = ≢ω : 2 ϴ α ω ⋄ 0 (αα ↑ ω) α (αα ↓ ω)}

     ws ← (' ', ⎕UCS 9) _set
    aws ← ws _any _ign
  awslf ← (⎕UCS 10 13) _set _o ws _any _ign
   gets ← aws _s ('←' _tk) _s aws _ign
    him ← '¯' _set
    dot ← '.' _set
    jot ← '∘' _set
   lbrc ← aws _s ('{' _set) _s aws
   rbrc ← aws _s ('}' _set) _s aws
   lpar ← aws _s ('(' _tk) _s aws _ign
   rpar ← aws _s (')' _tk) _s aws _ign
   lbrk ← aws _s ('[' _tk) _s aws _ign
   rbrk ← aws _s (']' _tk) _s aws _ign
   semi ← aws _s (';' _tk _as ('⍝' V∘,∘⊃)) _s aws
    grd ← aws _s (':' _tk) _s aws _ign
   egrd ← aws _s (':' ':' _tk) _s aws _ign
  alpha ← 'ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyzΔ' _set
 digits ← '0123456789' _set
   prim ← (prims ← '+-÷×|*⍟⌈⌊!<≤=≠≥>∧∨⍲⍱[]?⍴,⍪⌽⍉⍋⍒∈⍷⊃⍳○~≡≢⊢⊣/⌿\⍀↑↓∪∩⍧⍫⍛⍗⍠') _set
    mop ← '¨⍨/⌿⍀\⌺' _set
  dop₁ ← '.⍤∘' _set
  dop₂ ← '⍥⍤∘' _set
  dop₃ ← '∘' _set
    eot ← aws _s {'' ≡ ω : 0 ϴ α '' ⋄ 2 ϴ α ω} _ign
   digs ← digits _some
  odigs ← digits _any
    int ← aws _s digs _s (him _opt) _s aws
  float ← aws _s (odigs _s dot _s int _o (digs _s dot)) _s aws
   name ← aws _s (alpha _o (digits _some _s alpha) _some) _s aws
     aw ← aws _s ('⍺⍵' _set) _s aws
   aaww ← aws _s (('⍺⍺' _tk) _o ('⍵⍵' _tk)) _s aws
    sep ← aws _s (('⋄', ⎕UCS 10 13) _set _ign) _s aws
    nss ← awslf _s (':Namespace' _tk) _s aws _s (name _opt) _s awslf _ign
    nse ← awslf _s (':EndNamespace' _tk) _s awslf _ign
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    Sfn ← aws _s (('TFF□' _tk) _o ('TFFI□' _tk)) _s aws _as {P ⏀∈ω}
   Prim ← prim _as P
     Vt ← {((0 □ ⍉α) ⍳ ω) 1 □ α ⍨ '' ¯1}
    Var ← {α (aaww _o aw _o (name _as ⏀) _t (αα = Vt) _as (ωω V∘,∘⊃)) ω}
    Num ← float _o int _as (N∘⏀)
 Strand ← 0 Var 'a'  _s (0 Var 'a' _some) _as ('s' A∘⏀)
    Pex ← {α (rpar _s Ex _s lpar) ω}
   Atom ← Strand _o (0 Var 'a' _as ('v'A)) _o (Num _some _as ('n' A∘⏀)) _o Pex
    Brk ← rbrk _s {α (Ex _opt _s (semi _s (Ex _opt) _any)) ω} _s lbrk _as ('i' E∘⏀)
    Idx ← Brk _s (_yes _as {P ,'['}) _s Atom _as (2 E∘⏀)
   Blrp ← {α (αα _s (ωω Slrp ∇)) ω}
   Slrp ← {α (αα _o (ωω _s ∇) _o ((1 _eat) _s ∇)) ω}
     Fa ← {                          e ← ('ωω' 'αα', 'αω') ,∘⍨⍤1 ⍉ ¯1 + 3 3 2 2 ⊤ (6 4 4 ≠ 1 5 9) + 2 × ⍳ 14
                                     a ← e (α{ω Gex _o Ex _o Fex Stmts _then Fn⍨⍨ αα ⍨ α})⍤2 1 ⊢ ω
                                     m ← (0 = 0 □ ⍉a) ∧ ∧≠ (∨⍀ ∘.=⍨⍨ ⍳14) ∨ ∘.≠⍨⍨ 1 □ ⍉a
                           ~∨≠ m  :  (⌈≠ 0 □ ⍉a) ⍬ α ω
        (1 = +≠ m) ∧ 2 > m ⍳ 1  :  0 (,⊂('F' new 1) wrap ⊃⊃ m ≠ 1 □ ⍉a) α ω
                                     z ← ('F' new 'a') wrap ⊃ (m ≠ 'F' new¨ 1 + ⍳14) ⍨.(wrap∘⊃) m ≠ 1 □ ⍉a
                                         0 (,⊂z) α ω}
     Fn ← {                     ns ← n z ≠⍨⍨ m ← {(F_m ω) ∧ ¯1 ∈⍨⍨ k ω} z ← ⊃⍨⌿ ω ⋄ 0 = ≢ns : 0 (,⊂z) α ''
                                 p ← α∘Fa¨ ns ⋄ 0 < c ← ⌈⌿ ⊃¨p : c ⍬ α ω
                                     0 (⍨⌿ (⊂ 0 4 ⍴ ⍬) ,⍨⍨ p {ω ((d +∘⊃ ⊣), 1 ↓⍤⍤1 ⊢) ⊃⍨⌿ 1 ⊃ α}¨at{m} ↓z) α ''}
    Pfe ← {α (rpar _s Fex _s lpar) ω}
    Bfn ← rbrc Blrp lbrc _as ('F' new ¯1 ,∘⊂∘⏀ 1 ↓ ¯1 ↓ ⊢)
    Fnp ← Prim _o (1 Var 'f') _o Sfn _o Bfn _o Pfe
    Mop ← {α ((mop _as P) _s Afx _as (1 O)) ω}
  Dop₁ ← {α ((dop₁ _as P) _s Afx _as (2 O∘⏀)) ω}
  Dop₂ ← {α (Atom _s (dop₂ _as P) _s Afx _as (2 O∘⏀)) ω}
  Dop₃ ← (dop₃ _as P) _s Atom _as (2 O∘⏀) _o (dot _s jot _as (P∘⏀) _as (1 O))
    Bop ← {α (rbrk _s Ex _s lbrk _s (_yes _as {P ,'['}) _s Afx _as (2 O∘⏀)) ω}
    Afx ← Mop _o (Fnp _s (Dop₁ _o Dop₃ _opt) _as (⊃wrap/∘⏀)) _o Dop₂ _o Bop
    Trn ← {α (Afx _s ((Afx _o Idx _o Atom) _s (∇ _opt) _opt)) ω} _as ('t' F∘⏀)
   Bind ← {α (gets _s (name _as ⏀) _env (αα{(⊃⏀ω) αα ⍨ α}) _as (ωω new 'b', ⊢)) ω}
   Asgn ← gets _s Brk _s (name _as ⏀ _t (0 = Vt) _as ('a' V∘,∘⊃)) _as ('a' E∘⏀)
    Fex ← Afx _s (Trn _opt) _s (1 Bind 'F' _any) _as (⊃wrap/∘⏀)
    App ← Afx _s (Idx _o Atom _s (dop2 _not) _opt) _as {(≢ω) E ⏀ω}
     Ex ← Idx _o Atom _s {α (0 Bind 'E' _o Asgn _o App _s ∇ _opt) ω} _as (⊃wrap/∘⏀)
    Gex ← Ex _s grd _s Ex _as (G∘⏀)
   Nlrp ← sep _o eot Slrp (lbrc Blrp rbrc)
  Stmts ← {α (sep _any _s (Nlrp _then (αα _s eot∘⏀)) _any _s eot) ω}
     Ns ← nss Blrp nse _then (Ex _o Fex Stmts _then Fn) _s eot _as M

     ps ← {0 ≠ ⊃ c a e r ← (0 2 ⍴ ⍬) Ns ∈{ω /⍨⍨ ∧\ 'ᵃ' ≠ ω}¨ω ,¨ □UCS 10 : □SIGNAL c ⋄ (⊃a) e}
```

$$
\begin{aligned}
scp &\leftarrow (+\not\backslash F_m)\vdash\circ\subset\boxplus\vdash\\
prf &\leftarrow ((\not\equiv\uparrow{}^{-}1\downarrow\vdash(\not=\tilde{\cdot})\,0\neq\vdash)\ddot{\circ}1\uparrow\circ r)\vdash\\
blg &\leftarrow \{\alpha\leftarrow\vdash\diamond\alpha((prf\,(\lceil/\,(\iota\circ\not\equiv\vdash)\times\ddot{\circ}1\,(1\downarrow\dashv)\wedge.(=\vee\,0=\vdash)\circ\oslash\vdash)\,\alpha\alpha\,(\not=\circ\uparrow)\,r)\square\ddot{\circ}0\;2\;\omega\omega\,(\not=\tilde{\cdot})\,\alpha\alpha)\omega\}\\
enc &\leftarrow \subset\dashv,\circ\supset((\dashv,'\_',\vdash)/(\subset''),(\overline{\Phi}\ddot{\cdot}\vdash(/\tilde{\cdot})\,0\neq\vdash))\\
veo &\leftarrow \cup((\subset\texttt{'\%u'}),(,\ddot{\cdot}prims),\dashv)\sim\tilde{\circ}\{\supset,/\{\subset\bigstar(1\equiv\equiv\omega)\vdash\omega\}\ddot{\cdot}\omega\}\,{}^{-}1\downarrow\vdash(/\tilde{\cdot})\,(\wedge/\ddot{\cdot}\,0\neq((\supset 0\,\rho\vdash)\ddot{\cdot}\vdash))\\
ndo &\leftarrow \{\alpha\leftarrow\vdash\diamond m\supset\circ(\subset,\vdash)\ddot{\cdot}\,\alpha\circ\alpha\alpha''''\;\omega\supset\circ(,\circ\subset\tilde{\circ}\subset)\ddot{\cdot}\tilde{\cdot}\,m\leftarrow 1\geq\equiv\ddot{\cdot}\omega\}\\
n2f &\leftarrow (\supset,/)\,((1=\equiv)\supset,\circ\subset\tilde{\circ}\circ\subset)\ddot{\cdot}
\end{aligned}
$$

$$
\begin{aligned}
rn &\leftarrow\vdash,\circ\downarrow(1+d)\uparrow\ddot{\circ}{}^{-}1\,(+\not\backslash\,d\;\circ.=\circ\iota\,1+(\lceil/\,0,d))\\
rd &\leftarrow\vdash,(+/\uparrow\circ r\wedge.(=\vee\,0=\vdash)\circ\oslash\circ\uparrow\circ r\vdash(\not=\tilde{\cdot})\,F_m\wedge 1\in\tilde{\cdot}\,k)\\
df &\leftarrow\vdash(\not=\tilde{\cdot})\,(+\backslash 1=d)\,(\sim\dashv\in\dashv(/\tilde{\cdot})\,(1=d)\wedge(\sim\texttt{'b'}\in\tilde{\cdot}\,k)\wedge O_m\vee F_m)\vdash\\
dua &\leftarrow((\sim G_m)\wedge F_m\vee\downarrow\circ prf\in r\circ F_s)\,(\dashv(\not\backslash\circ\vdash)\,(d\,(\not=\tilde{\cdot})\,\dashv)\,(0,1\downarrow(\bar{}1\oplus\vdash)\wedge\dashv=\bar{}1\oplus\dashv)\dashv(\not=\circ\vdash)\,0\in\tilde{\cdot}\,n)\vdash\\
du &\leftarrow\vdash(\not=\tilde{\cdot}\circ\sim)\,dua\vee\circ(\vee/)\,(prf\wedge.(=\vee\,0=\vdash)\circ\oslash\,prf\,(\not=\tilde{\cdot})\,dua)\wedge\uparrow\circ r\wedge.\geq\circ\oslash\,dua\,(\not=\circ\vdash)\uparrow\circ r\times 0=prf\\
lfh &\leftarrow(0\neq 1\square\dashv)\supset(\subset\circ\oslash\circ\fatsemi\,0\,\texttt{'M'}\,0\,'',0,\tilde{\cdot}\,(\subset\dashv))\,,\circ\subset\circ\oslash\circ\fatsemi\,1\,\texttt{'F'}\,1,('fn'\,enc\dashv),(\subset\dashv),5\downarrow\circ,1\uparrow\vdash\\
lfn &\leftarrow(d,\texttt{'Of'},3\downarrow\vdash)\ddot{\circ}1\,at\,(F_m\wedge\texttt{'b'}\in\tilde{\cdot}\,k)\,(d,\texttt{'Vf'},('\texttt{fn}'\,enc\circ\supset r),4\downarrow\vdash)\ddot{\circ}1\,at\,(F_m\wedge 1\in\tilde{\cdot}\,k)\\
lf &\leftarrow(\supset\fatsemi/)\,(1,1\downarrow F_m\wedge 1\in\tilde{\cdot}\,k)\,blg\,(\uparrow r)\,(\subset lfh\fatsemi\circ(((\vdash-(\supset-2\lfloor\supset))\,d),1\downarrow\ddot{\circ}1\vdash)\,lfn)\boxplus 1\downarrow\vdash\\
dn &\leftarrow((0\in\tilde{\cdot}\,n)\wedge(A_m\wedge\texttt{'v'}\in\tilde{\cdot}\,k)\vee O_m\wedge\texttt{'f'}\in\tilde{\cdot}\,k)\,((\sim\dashv)\,(\not=\circ\vdash)\,(d-\bar{}1\oplus\dashv),1\downarrow_{[1]}\vdash)\vdash\\
mrep &\leftarrow(1+\supset),\texttt{'P'}\,0\,(,'\vdash'),(\subset'')\,,\tilde{\cdot}\,\bar{}1\downarrow 4\downarrow\circ,1\uparrow\vdash\\
mreu &\leftarrow\supset,\texttt{'E'}\,'\texttt{u}',(\subset'')\,,\tilde{\cdot}\,\bar{}1\downarrow 3\downarrow\circ,1\uparrow\vdash\\
mre &\leftarrow(\supset\fatsemi/)\,(-\circ\supset V_m\vee A_m)\circ\supset\circ\oplus\,(\downarrow,(((\vdash\rho\tilde{\cdot}\,(\not\equiv\oslash)\,,\tilde{\cdot}\not\equiv\times 2<\not\equiv)\,mreu\fatsemi mrep\fatsemi(1+\mathrm{d}),1\downarrow\ddot{\circ}1\vdash)\ddot{\cdot}\uparrow))\vdash\\
mrs &\leftarrow\vdash\subset_{[0]}\tilde{\cdot}\,1,1\downarrow d=1+\circ\supset d\\
mrk &\leftarrow(-\circ(+/\wedge\backslash)\circ\oplus L_m)\,(\uparrow\fatsemi\tilde{\circ}\circ(mre\,(mre\,mrs)\ddot{\cdot}\,at\,(G_m\circ(\supset\fatsemi/)\,1\uparrow\ddot{\cdot}\vdash)\circ mrs)\downarrow)\vdash\\
mr &\leftarrow(\supset\fatsemi/)\,((1\uparrow\vdash),(mrk\ddot{\cdot}\,1\downarrow\vdash))\circ scp\\
ur &\leftarrow((2\uparrow\vdash),1,(\texttt{'um'}\,enc\circ\supset r),4\downarrow\vdash)\ddot{\circ}1\,at\,(E_m\wedge\texttt{'u'}\in\tilde{\cdot}\,k)\\
rt &\leftarrow\vdash,(\vee\backslash F_m)+(+\not=prf\wedge.(=\vee\,0=\dashv)\circ\oslash\tilde{\circ}\circ\uparrow\circ r\,M_s\fatsemi G_s)-F_m\\
nm &\leftarrow((3\uparrow\vdash),(\texttt{'fe'}\,enc\circ\supset r),4\downarrow\vdash)\ddot{\circ}1\,at\,((0\in\tilde{\cdot}\,n)\wedge E_m\vee O_m\vee A_m)\\
lgg &\leftarrow(\fatsemi/1\downarrow\vdash)\fatsemi\circ\supset\tilde{\cdot}\,\dashv(((\bar{}1+d),2,\tilde{\cdot}\,t,k,n,r\,,\circ\fatsemi\,s)\fatsemi\dashv\fatsemi 3,\texttt{'V'},\texttt{'a'},3\,(\downarrow\ddot{\circ}1)\,1\uparrow\vdash)\circ\supset 1\uparrow\vdash\\
lg &\leftarrow(\supset\fatsemi/)\vdash((\subset\dashv(\not=\tilde{\cdot}\circ\sim)\,(\vee\backslash\vdash)),(((1\uparrow\vdash)\,lgg\vdash\subset_{[0]}\tilde{\cdot}\,d=1+\supset)\ddot{\cdot}\subset_{[0]}\tilde{\cdot}))\,G_m\wedge 1\oplus E_m\\
fet &\leftarrow(d,\texttt{'V'}\,0,3\downarrow\vdash)\ddot{\circ}1\,at\,(0,1\downarrow E_m\vee O_m\vee A_m)\,(d,\texttt{'Av'},3\downarrow\vdash)\ddot{\circ}1\,at\,(E_m\wedge\texttt{'b'}\in\tilde{\cdot}\,k)\\
fee &\leftarrow(\fatsemi/\oplus)\,(M_m\vee E_m\vee O_m\vee A_m)\,blg\vdash((\supset\circ\oplus\vdash)\,(\subset(d--\tilde{\circ}\circ\supset),1\downarrow\ddot{\circ}1\vdash)\circ fet\dashv\fatsemi\bar{}1\downarrow\ddot{\circ}1\vdash)\boxplus\supset,\tilde{\cdot}\,1\downarrow\vdash\\
fe &\leftarrow(\supset\fatsemi/)\,(+\not\backslash\,d\leq g)\,(\subset(\vdash\uparrow\tilde{\cdot}\,1=\circ\not\equiv\vdash)\,\fatsemi\circ\supset\circ fee\vdash)\boxplus\vdash\\
can &\leftarrow(+\backslash A_m\vee O_m)\,((,1\uparrow\vdash),\circ(\subset(\bar{}1+2\lfloor\not\equiv)\supset(\subset\circ\subset\supset),\subset)\circ n\,1\downarrow\vdash)\boxplus\vdash\\
cas &\leftarrow(\bar{}1\oplus(A_m\vee O_m)\wedge\texttt{'vf'}\in\tilde{\cdot}\,k)\vee(\downarrow prf)\in\circ r\vdash(\not=\tilde{\cdot})\,A_m\wedge\texttt{'n'}\in\tilde{\cdot}\,k\\
ca &\leftarrow(can\vdash(\not=\tilde{\cdot})\,cas\vee A_m\vee O_m\wedge\texttt{'f'}\in\tilde{\cdot}\,k)\dashv at\,(A_m\vee O_m\wedge\texttt{'f'}\in\tilde{\cdot}\,k)\,\theta\,,\circ\subset\tilde{\circ}\vdash(\not=\tilde{\cdot}\circ\sim)\,cas\\
lj &\leftarrow(\supset\fatsemi/)\,(1\uparrow scp),((\vdash\fatsemi 2\,\texttt{'L'}\,0\,0,2\,'',\tilde{\cdot}\,\bar{}2\downarrow 4\downarrow\circ,1\uparrow\vdash)\ddot{\cdot}\,1\downarrow scp)\\
sd &\leftarrow(\supset\fatsemi/)\,(1\uparrow scp),(n\,F_s)\,(d,\texttt{'Vf'},(\subset\dashv),4\downarrow\vdash)\ddot{\circ}1\,at\,((\subset,\texttt{'}\forall\texttt{'})\in\tilde{\cdot}\,n)\ddot{\cdot}\,1\downarrow scp\\
inm &\leftarrow\vee\not=\bar{}1\,(\oplus\vee\vdash)\,1\,2\,(\oplus\vee\vdash)\,(\bar{}1\;\bar{}2\oplus E_m\wedge_{[1]}1\,2\circ.=k)\wedge\ddot{\circ}1\,V_m\wedge n\in\circ n\,F_s\\
inp &\leftarrow(E_m\wedge\dashv)\vee 1,2\neq/\dashv\\
inza &\leftarrow(1\uparrow 1\downarrow\dashv)\,(\not=\tilde{\cdot}\circ\not\equiv)\,at\,((\subset,\texttt{'}\alpha\texttt{'})\in\tilde{\cdot}\,n)\,(\bar{}1\uparrow\dashv)\,(\not=\tilde{\cdot}\circ\not\equiv)\,at\,((\subset,\texttt{'}\omega\texttt{'})\in\tilde{\cdot}\,n)\vdash\\
inz &\leftarrow(1\uparrow\dashv)\,(d,t,k,3\downarrow\ddot{\circ}1\,(\not=\tilde{\cdot}\circ\not\equiv))\,at\,(0\,,\tilde{\cdot}\,2\neq/\circ\oplus(\vee\backslash\circ\oplus E_m))\,inza\\
inn &\leftarrow(3\uparrow\ddot{\circ}1\vdash),((\dashv\rho\ddot{\cdot}\tilde{\cdot}\,1+0\lceil(\lceil/\circ n\,G_s))\,(('\texttt{fe}'\equiv 2\uparrow\vdash)\supset(\subset\vdash)\,,\circ\subset\texttt{'fe'},(\overline{\Phi}\dashv),2\downarrow\vdash)\ddot{\cdot}\,n),(4\downarrow\ddot{\circ}1\vdash)\\
ins &\leftarrow\dashv(d,t,k,((1000\times 1+\dashv)+1+n+(\lceil/n)),4\downarrow\ddot{\circ}1\vdash)\,at\,(L_m\vee G_m)\,inn\\
inr &\leftarrow 1\,,\circ\fatsemi\vdash inz\ddot{\cdot}\,(\iota\circ\not\equiv\vdash)\,ins\ddot{\cdot}\,((\supset\circ n\ddot{\cdot}\,\dashv)\,\iota((\supset n(\not=\tilde{\cdot})\,V_m\wedge\texttt{'f'}\in\tilde{\cdot}\,k)\ddot{\cdot}\vdash))\supset\ddot{\cdot}\,(\subset 1\downarrow\ddot{\cdot}\,\dashv)\,,\circ\subset\ddot{\cdot}\vdash\\
in &\leftarrow(\supset\fatsemi/)\circ(\vdash/)\,(1\downarrow scp)\,inr\circ((0\,\rho\subset 0\,8\,\rho\,0),\vdash/)\,at\,(\dashv/)\,inm\,((\supset\ddot{\cdot}\,inp\subset E_m\wedge\dashv)\,,\circ\fatsemi\,inp\subset_{[0]}\vdash)\vdash
\end{aligned}
$$

```
pcc ← (⊂⊢(⌿⍨) A_m ∨ O_m ∧ 'f' ∊⍨ k)∘((⍳∘∪⍨ n) ⎕⍤0 2 (1 ⌈ ≢) ↑ ⊢)∘(⊃⍪⌿)∘⌽ (⌿∘⊢)
pcb ← ((, ∧.(= ∨ 0 = ⊣)∘⍪)⍤2 1⍨∘↑∘r M_s ⍪ F_s) pcc⍤1 ((⊢ (⌿⍨) (d = g) ∧ A_m ∨ E_m ∨ O_m)¨ scp)
pcv ← (d, 'V', ('af' ⊃¨∘⊂⍨ O_m), (⊃¨v), r, s, (⊂⍬) ,⍨∘⍪ g) at (O_m ∨ A_m ∧ 'v' ∊⍨ k)
pc ← (⊃⍪/) pcb {(pcv d (⊣, 1 ↓⍤1 ⊢)(α ↑⍨ 1 ⌈ ≢α) ⎕⍤0 2⍨ (n α) ⍳ n) at (V_m ∧ (n α) ∊⍨ n) ω}¨ scp
da ← ⊢ (⌿⍨∘~) (A_m ∧ d = g) ∨ (0 ,⍨ 2 ∧/ L_m) ∨ (L_m ∧ ¯1 ⌽ A_m ∧ d = g) ∨ O_m ∧ ('f' ∊⍨ k) ∧ 1 ≠ d
fce ← (⊃∘n P_s) {⊂⍕ 'ω' ,⍨ (≢ω) ⊃ '' (α, '⊃') ('⊃', α, '/')} (v A_s)
fcm ← (∧/ E_m ∨ A_m ∨ P_m) ∧∘~ 'ui' ∊⍨∘⊃∘⊃ k
fc ← ((⊃⍪/) (((d, 'An', 3 ↓ ¯1 ↓ ,) 1 ↑ ⊢), fce)¨ at (fcm¨)) ('MFOEL' ∊⍨ t) ⊂[0] ⊢
ce ← (+\ F_m ∨ G_m ∨ E_m ∨ O_m ∨ L_m) ((¯1 ↓∘, 1 ↑ ⊢) ,∘⊂ (⊃∘v 1 ↑ ⊢) ,∘(A_m ⊃¨∘↓ n ,∘⍪∘n2f v) 1 ↓ ⊢)⌸ ⊢
ll ← (⊢ (⌿⍨) 1 ⌽ L_m) (((⊂⊂'%l') ,∘⊂¨∘n ⊣) ,⍨ ¯1 ↓⍤1 ⊢) at L_m ⊢
fv ← (⊃⍪/) (((1 ↓ ⊢) ⍪⍨ (, 1 7 ↑ ⊢) ,∘⊂∘n ¯1 ↑ ⊢)¨ scp)
nv ← (¯1 ↓⍤1 ⊢), (¯1 ⊖ ≢ ⊃ ⊢ ,∘⊂⍨ (⊂'%u' '%f' '%u'), (⊂ '%u' '%i', ⊢), (⊂ (⊂'%u'), ⊢))¨∘v
lt ← (⊂⍬) ,⍨ ⊢
val ← (n ⍳∘∪ n) ,¨ ⊢ (⊢ + (≢⊣) × 0 = ⊢) (⌈/ (⍳≢) ×⍤1 (∪n) ∘.((⊂⊣) ∊ ⊢) (n2f¨ v))
vag ← ∧∘~∘(∘.=⍨∘⍳ ≢)⍨ (∘.(((1 ⎕ ⊢) > 0 ⎕ ⊣) ∧ (0 ⎕ ⊢) < 1 ⎕ ⊣)⍨ val)
vae ← (∪n) (⊣ ,⍤0 ⊣ (⎕⍨⍤1 0)∘⊃ ((⊢ ,∘⊃ (⍳∘≢ ⊣) ~ ⊢ (⌿⍨) (≢⊢) ↑ ⊣)/∘⌽ (⊂⍬) ,∘↓ ⊢)) vag
vac ← (((0 ⎕∘⍉ ⊣) ⍳∘⊂ ⊢) ⊃ (1 ⎕∘⍉ ⊣) ,∘⊂ ⊢) ndo
va ← ((⊃⍪/) (1 ↑ ⊢), (((vae E_s) (d, t, k, (⊣ vac n), r, s, g, y ,∘⍪⍨ (⊂⊣) vac¨ v) ⊢)¨ 1 ↓ ⊢)) scp
avb ← {(((,¨'αω') ↑⍨ 1 ↓ ρ) ⍪ ⊢) α ⎕⍨⍤2 0 ⊢ αα ⍳ αα ∩⍨ (↓ (⌽ 1 +∘⍳ 0 ⍳⍨ ⊢) ((≢⊢) ↑ ↑)⍤0 1 ⊢) ⊃ r ω}
avi ← ¯1 0 + (ρ⊣) ⊤ (,⊣) ⍳ (⊂⊢)
avh ← {⊂ ω, (nω) ((αα (ωω avb) ω) {αα avi ndo (⊂α), ω})¨ v ω}
av ← (⊃⍪/) (+\ F_m) {α((α ((∪∘⌽ (0 ρ ⊂''), n) E_s)⌸ ω) avh (r (1 ↑ ω) ⍪ F_s ω))⌸ ω} ⊢
rlf ← (⌽ ↓ (((1 ⊃ ⊣) ∪ ⊢ ~ 0 ⎕ ⊣)/∘⌽ (⊂⍬), ↑)⍤0 1⍨ 1 +∘⍳ ≢) (⊖ 1 ⊖ n ,⍤0 (⊂⊣) veo¨ v)
rl ← ⊢ ,∘(⊃,/) (⊂∘n O_s ⍪ F_s) rlf¨ scp
vc ← (⊃⍪/) (((1 ↓ ⊢) ⍪⍨ (1 7 ↑ ⊢), (≢∘∪∘n E_s), 1 ¯3 ↑ ⊢)¨ scp)
eff ← (⊃⍪/) ⊢ (((⊂∘⍉∘⍪ d, 'Fe', 3 ↓ ,) 1 ↑ ⊣), 1 ↓ ⊢) (d =∘⊃ d) ⊂[0] ⊢
ef ← (F_m ∧ ¯1 =∘×∘⊃¨ y) ((⊃⍪/) (⊂ ⊢ (⌿⍨)∘~ (∨\ ⊣)), (eff¨ ⊂[0])) ⊢
ifn ← 1 'F' 0 'Init' ⍬ 0 1, (4 ρ 0) ⍬ ⍬ ,⍨ ⊢
if ← (1 ↑ ⊢) ⍪ (⊢ (⌿⍨) O_m ∧ 1 = d) ⍪ ((⊢ wrap⍨∘ifn∘≢∘∪ n) ⊢ (⌿⍨) E_m ∧ 1 = d) ⍪ (∨\ F_m) (⌿∘⊢) ⊢
fgz ← (1 ↑ ⊢) ⍪ (((¯1 + d), 1 ↓⍤1 ⊢) 1 ↓ ⊢) ⍪ 2, 'G', 1, 3 ↓⍤1 (¯1 ↑ ¯1 ↓⍤1 ⊢) ,∘n 1 ↑ ⊢
fg ← (⊃⍪/) (fgz¨ at (G_m∘(⊃⍪/) 1 ↑¨ ⊢) ⊢ ⊂[0]⍨ d = 2 ⌊ g)
fft ← (, 1 ↑ ⊢) (1 'Z', (2 ↓ ¯5 ↓ ⊣), (v⊣), n, y, (⊂ 2 ↑∘,∘⊃∘⊃ e), l) (¯1 ↑ E_s)
ff ← ((⊃⍪/) (1 ↑ ⊢), (((1 ↑ ⊢) ⍪ (((¯1 + d), 1 ↓⍤1 ⊢) 1 ↓ ⊢) ⍪ fft)¨ 1 ↓ ⊢)) scp
fzh ← ((∪n) ∩ (⊃∘l ⊣)) (¯1 ⌽ (⊂⊣), ((≢⊢) - 1 + (⌽n) ⍳ ⊣) ((⊂ ⊣ ⊃¨∘⊂ (⊃¨e)), (⊂ ⊣ ⊃¨∘⊂ (⊃¨y)) ,∘⊂ ⊣) ⊢) ⊢
fzf ← 0 ≠ (≢∘ρ¨∘⊃∘v ⊣)
fzb ← (((⊃∘v ⊣) (⌿⍨) fzf), n) ,∘⍪ ('f'∘,∘⍕¨∘⍳ (+/fzf)), ('s'∘,∘⍕¨∘⍳∘≢ ⊢)
fzv ← ((⊂⊣) (⊖↑)⍨¨ (≢⊣) (- +∘⍳ ⊢) (≢⊢)) ((⊢ ,⍨ 1 ⎕∘⍉ ⊣) ⎕⍨ (0 ⎕∘⍉ ⊣) ⍳ ⊢)⍤2 0¨ v
fze ← (¯1 + d), t, k, fzb ((⊢/ (-∘≢ ⊢) ↑ ⊣), r, s, g, fzv, y, e ,∘⍪ l) ⊢
fzs ← (, 1 ↑ ⊢) (1 ⊖ (⊣ ((1 'Y', (2 ⎕ ⊣), ⊢) ⍪∘⍉∘⍪ (3 ↑ ⊣), ⊢) 1 ⌽ fzh, ¯1 ↓ 6 ↓ ⊣) ⍪ fze) (⌿∘⊢)
fz ← ((⊃⍪/) (1 ↑ ⊢), (((2 = d) (fzs ⍪ (1 ↓∘~ ⊣) (⌿∘⊢) 1 ↓ ⊢) ⊢)¨ 1 ↓ ⊢)) (1, 1 ↓ S_m) ⊂[0] ⊢
fd ← (1 ↑ ⊢) ⍪ ((1, 'Fd', 3 ↓ ⊢)⍤1 F_s) ⍪ 1 ↓ ⊢

tta ← (fc∘da∘(pc⍣≡)∘mr⍣≡)∘in⍣3∘sd∘lj∘ca∘fe∘lg∘nm∘rt∘mr∘dn∘lf∘du∘df∘rd∘rn
tt ← fd∘fz∘ff∘fg∘if∘ef∘vc∘rl∘av∘va∘lt∘nv∘fv∘ll∘ce∘ur∘tta
```

```
E₁ ← {'fn' gcl ((⊂ n ,∘⊃ v), e, y) ω}
E₂ ← {'fn' gcl ((⊂ n ,∘⊃ v), e, y) ω}
Eᵢ ← {r l f ← ⊃ v ω ⋄ ((⊃ n ω) ('fn' var) ⊃⊃ e ω), '=', ((⊃⊃ v ω) ('fn' var) 1 ⊃ ⊃ e ω), ';', nl}
O₁ ← {'op' gcl ((⊂ n ,∘⊃ v), e, y) ω}
O₂ ← {'op' gcl ((⊂ n ,∘⊃ v), e, y) ω}
O₀ ← {''}
Oᵣ ← {'EF(', ('Δ' □R '__' ⊃ n ω), ',', (⊃⊃ v ω), ');', nl}
F_d ← {'FP(', (⊃ n ω), ');', nl}
F₀ ← {'DF(', (⊃ n ω), '_f){', nl, 'A*env[]={tenv};', nl}
F₁ ← {'DF(', (⊃ n ω), '_f){', nl, ('env0' dnv ω), (fnv ω)}
G₀ ← {v ← (⊃⊃ v ω) ('' var) 1 ⊃ ⊃ e ω
        'if(1!=cnt(', v, '))err(5);if(', v, '.v.as(s32).scalar<I>()){', nl}
G₁ ← {'z=', ((⊃ n ω) ('' var) ⊃ ⊃ e ω), ';goto L', (⍤⊃ l ω), ';}', nl}
L₀ ← {'z=', a, ';L', (⍤⊃ n ω), ':', (a ← (1 ⊃ ⊃ v ω) ('' var) 1 ⊃ ⊃ e ω), '=z;', nl}
Z₀ ← {'}', nl, nl}
Z₁ ← {'}', nl, nl}
Z_e ← {'}', nl, nl}
M₀ ← {(rth θ), ('tenv' dnv ω), nl, 'A*env[]={', ((0 ≡ ⊃ω) ⊃ 'tenv' 'NULL'), '};', nl, nl}
S₀ ← {(('{', rk0, srk, 'DO(i,prk)cnt*=sp[i];', spp, sfv, slp) ω)}
Y₀ ← {⊃,/ ((ι ≢ ⊃ n ω) ((⊣ sts¨ (⊃l) ,¨∘⊃ s), '}', nl, ⊣ ste¨ (⊃n) var¨∘⊃ r) ω), '}', nl}

gc ← {⊃,/ {0 = ⊃ t ω : ⊂ 5 ρ θ ⋄ ⊂ (⍏ (⊃ t ω), ⍤ ⊃ k ω) ω}⍤1 ⊢ ω}
```

syms ← ,¨	'+'	'−'	'×'	'÷'	'⋆'	'⍟'	'|'	'○'	'⌊'	'⌈'	'!'
nams ←	'add'	'sub'	'mul'	'div'	'exp'	'log'	'res'	'cir'	'min'	'max'	'fac'
syms ,← ,¨	'<'	'≤'	'='	'≥'	'>'	'≠'	'~'	'∧'	'∨'	'⍲'	'⍱'
nams ,←	'lth'	'lte'	'eql'	'gte'	'gth'	'neq'	'not'	'and'	'lor'	'nan'	'nor'
syms ,← ,¨	'□'	'['	'ι'	'ρ'	','	'⍪'	'⌽'	'⍉'	'⍳'	'∈'	'⍷'
nams ,←	'sqd'	'brk'	'iot'	'rho'	'cat'	'ctf'	'rot'	'trn'	'rtf'	'mem'	'dis'
syms ,← ,¨	'≡'	'≢'	'⊢'	'⊣'	'⊤'	'⊥'	'⌿'	'≠'	'\'	'⍀'	'?'
nams ,←	'eqv'	'nqv'	'rgt'	'lft'	'enc'	'dec'	'red'	'rdf'	'scn'	'scf'	'rol'
syms ,← ,¨	'↑'	'↓'	'⍫'	'⍒'	'.'	'⍤'	'⍣'	'∘'	'⍵'	'⍺'	
nams ,←	'tke'	'drp'	'map'	'com'	'dot'	'rnk'	'pow'	'jot'	'unq'	'int'	
syms ,← ,¨	'⍋'	'⍒'	'∘.'	'⍷'	'⊂'	'⌸'	'□FFT'	'□IFFT'	'%u'		
nams ,←	'gdu'	'gdd'	'oup'	'fnd'	'par'	'mdv'	'fft'	'ift'	''		

```
nl ← □UCS 13 10 ⋄ fvs ← ,⍤0 (≠⍤) 0 ≠ (≢∘ρ¨ ⊣) ⋄ cln ← '¯' □R '-' ⋄ cnm ← (syms ι ⊂) ⊃ (nams, ⊂)
lits ← {'A(0,eshp,constant(', (cln ⍤ ω), ',eshp,', ('f64' 's32' ⊃⍤ ω = ⌊ω), '))'}
litv ← {'std::vector<', ('DI' ⊃⍤ ∧/ ω = ⌊ω), '>{', (cln ⊃ {α, ',', ω}/ ⍤¨ ω), '}.data()'}
lita ← {'A(1,dim4(', (⍤≢ω), '),array(', (⍤≢ω), ',', (litv ω), '))'}
lit ← {'  ' = ⊃ 0 ρ ω : (cnm ω), α ⋄ 1 = ≢ω : lits ω ⋄ lita ω}
var ← {α ≡ ,'α' : ,'ι' ⋄ α ≡ ,'ω' : ,'r' ⋄ ¯1 ≥ ⊃ω : αα lit ,α ⋄ 'env[', (⍤⊃ω), '][', (⍤⊃ ⌽ω), ']'}
dnv ← {(0 ≡ z) ⊃ ('A  ', α, '[', (⍤ z ← ⊃ v ω), ];') ('A*', α, '=NULL;')}
fnv ← {z ← 'A*env[', (⍤ 1 + ⊃ s ω), ']={', (⊃,/ (⊂'env0'), {',p[', (⍤ω), ']'}¨ ι ⊃ s ω), '};', nl}
gcl ← {z r l n ← ((3 ρ ⊂'fn'), ⊂α) {⊃ α var/ ω}¨ ↓ (⊃ω), ⍪ 1 ⊃ ω ⋄ n, '(', (⊃{α, ',', ω}/ z l r ~ ⊂'fn'), ',env);', nl}
```

```
∇ Z ← Gfx∆Init S
  'w_new'    ⎕NA 'P  ', (S, soext 0), '|w_new <C[]'
  'w_close'  ⎕NA 'I  ', (S, soext 0),'|w_close P'
  'w_del'    ⎕NA (S, soext 0), '|w_del P'
  'w_img'    ⎕NA (S, soext 0), '|w_img <PP P'
  'w_plot'   ⎕NA (S, soext 0), '|w_plot <PP P'
  'w_hist'   ⎕NA (S, soext 0), '|w_hist <PP F8 F8 P'
  'loadimg'  ⎕NA (S, soext 0), '|loadimg >PP <C[] I'
  'saveimg'  ⎕NA (S, soext 0), '|saveimg <PP <C[]'
  Z ← 0 0 ⍴ 0
∇

    Display ← {α ← 'Co-dfns' ⋄ W ← w_new ⊂α ⋄ 777 :: w_del W
                   w_del W ⊣ W αα{w_close α : ⍎'⎕SIGNAL 777' ⋄ α αα ω}⍣⍥ωω ⊢ ω}
LoadImage ← {α ← 1 ⋄ ⍁ loadimg 0 ω α}
SaveImage ← {α ← 'image.png' ⋄ saveimg (⍁ω) α}
    Image ← {~ 2 3 ∨.= ≢⍴ω : ⎕SIGNAL 4 ⋄ (3 ≠ 2 ⊃ 3 ↑ ⍴ω) ∧ 3 = ≢⍴ω : ⎕SIGNAL 5 ⋄ ω ⊣ w_img (⍁ω) α}
     Plot ← {2 ≠ ≢⍴ω : ⎕SIGNAL 4 ⋄ ~ 2 3 ∨.= 1 ⊃ ⍴ω : ⎕SIGNAL 5 ⋄ ω ⊣ w_plot (⍁ω) α}
Histogram ← {ω ⊣ w_hist ω, α}

∇ r          ← List
  r          ← ⎕NS⍨ 1 ⍴ ⊂0 ⋄ r.Name ← ,⍨ ⊂'Compile' ⋄ r.Group←⊂ 'CODFNS'
  r[0].Desc  ← 'Compile an object using Co-dfns'
  r.Parse    ← ⊂ '2S -af=cpu opencl cuda '
∇

Convert ← {α (⎕SE.SALT.Load '[SALT]/lib/NStoScript -noname').ntgennscode ω}
Run     ← {C I ← ω ⋄ in out ← I.Arguments ⋄ AF∆LIB ⍤← I.af'' ⊃⍨ I.af ≡ 0
           S ← (⊂ ':Namespace ', out), 2 ↓ 0 0 0 out Convert ##.THIS.⍎ in
           'Compile' ≡ C : {} {_ ← {##.THIS.⍎ out, '←ω'} out Fix S ⊣ ⎕EX '##.THIS.', out
              ⎕CMD 'copy "%CUDA_PATH%\nvvm\bin\nvvm64*" /Y' /⍨ (I.af ≡ 'cuda') ∧ opsys 1 0 0} 0}
Help    ← {'Usage: <object> <target> [-af={cpu,opencl,cuda}]'}
```

rth ← {⊃,/ (⊂*nl*) ,⍤⍨ 2 ↓⍤¯2 ↓ *c* ↓⍨ 1 + (⊂'rth') ⍳⍨ 3 ↑⍤⍨ *c* ← ⎕SRC ⎕THIS}

```
⍝ #include <time.h>
⍝ #include <stdint.h>
⍝ #include <inttypes.h>
⍝ #include <limits.h>
⍝ #include <float.h>
⍝ #include <math.h>
⍝ #include <memory>
⍝ #include <algorithm>
⍝ #include <string>
⍝ #include <cstring>
⍝ #include <vector>
⍝ #include <unordered_map>
⍝ #include <arrayfire.h>
⍝ using namespace af;
⍝
⍝ #if AF_API_VERSION < 35
⍝ #error "Your ArrayFire version is too old."
⍝ #endif
⍝ #ifdef _WIN32
⍝  #define EXPORT extern "C" __declspec(dllexport)
⍝ #elif defined(__GNUC__)
⍝  #define EXPORT extern "C" __attribute__ ((visibility ("default")))
⍝ #else
⍝  #define EXPORT extern "C"
⍝ #endif
⍝ #ifdef _MSC_VER
⍝  #define RSTCT __restrict
⍝ #else
⍝  #define RSTCT restrict
⍝ #endif
⍝ #define S struct
⍝ #define Z static
⍝ #define R return
⍝ #define RANK(lp) ((lp)->p->r)
⍝ #define TYPE(lp) ((lp)->p->t)
⍝ #define SHAPE(lp) ((lp)->p->s)
⍝ #define ETYPE(lp) ((lp)->p->e)
⍝ #define DATA(lp) ((V*)&SHAPE(lp)[RANK(lp)])
⍝ #define CS(n,x) case n:x;break;
⍝ #define DO(n,x) {I i=0,_i=(n);for(;i<_i;++i){x;}}
⍝ #define DOB(n,x) {B i=0,_i=(n);for(;i<_i;++i){x;}}
⍝
⍝ typedef enum{APLNC=0,APLU8,APLTI,APLSI,APLI,APLD,APLP,APLU,APLV,APLW,APLZ,
⍝  APLR,APLF,APLQ}APLTYPE;
⍝ typedef long long L;typedef int I;typedef int16_t S16;typedef int8_t S8;
⍝ typedef double D;typedef unsigned char U8;typedef unsigned U;
⍝ typedef dim_t B;typedef cdouble DZ;typedef void V;typedef std::string STR;
⍝
⍝ S{U f=3;U n;U x=0;wchar_t*v=L"Co-dfns";const wchar_t*e;V*c;}dmx;
⍝ S lp{S{L l;B c;U t:4;U r:4;U e:4;U _:13;U _1:16;U _2:16;B s[1];}*p;};
⍝ S dwa{B z;S{B z;V*(*ga)(U,U,B*,S lp*);V(*p[16])();V(*er)(V*);}*ws;V*p[4];};
⍝ S dwa*dwafns;Z V derr(U n){dmx.n=n;dwafns->ws->er(&dmx);}
⍝ EXPORT I DyalogGetInterpreterFunctions(dwa*p){
⍝  if(p)dwafns=p;else R 0;if(dwafns->z<sizeof(S dwa))R 16;R 0;}
⍝ Z V err(U n,wchar_t*e){dmx.e=e;throw n;}Z V err(U n){dmx.e=L"";throw n;}
⍝ S A{I r;dim4 s;array v;A(I r,dim4 s,array v):r(r),s(s),v(v){}
⍝  A():r(0),s(dim4()),v(array()){}};
⍝ int isinit=0;dim4 eshp=dim4(0,(B*)NULL);std::wstring msg;
```

```
A #define NM(n,nm,sm,sd,di,mf,df,ma,da) S n##_f:FN{di;mf;df;ma;da;\
A  n##_f(STR s,I m,I d):FN(s,m,d){}} n##fn(nm,sm,sd);
A #define OM(n,nm,sm,sd,mf,df) S n##_o:MOP{mf;df;\
A  n##_o(FN&l,A*p[]):MOP(nm,sm,sd,l,p){}};
A #define OD(n,nm,sm,sd,mf,df) S n##_o:DOP{mf;df;\
A  n##_o(FN&l,FN&r,A*p[]):DOP(nm,sm,sd,l,r,p){}\
A  n##_o(const A&l,FN&r,A*p[]):DOP(nm,sm,sd,l,r,p){}\
A  n##_o(FN&l,const A&r,A*p[]):DOP(nm,sm,sd,l,r,p){}};
A #define MT
A #define DID inline array id(dim4)
A #define MFD inline V operator()(A&,const A&,A*[])
A #define MAD inline V operator()(A&,const A&,D,A*[])
A #define DFD inline V operator()(A&,const A&,const A&,A*[])
A #define DAD inline V operator()(A&,const A&,const A&,D,A*[])
A #define DI(n) inline array n::id(dim4 s)
A #define ID(n,x,t) DI(n##_f){R constant(x,s,t);}
A #define MF(n) inline V n::operator()(A&z,const A&r,A*p[])
A #define MA(n) inline V n::operator()(A&z,const A&r,D ax,A*p[])
A #define DF(n) inline V n::operator()(A&z,const A&l,const A&r,A*p[])
A #define DA(n) inline V n::operator()(A&z,const A&l,const A&r,D ax,A*p[])
A #define SF(n,x) inline V n::operator()(A&z,const A&l,const A&r,A*p[]){\
A  if(l.r==r.r&&l.s==r.s){\
A   z.r=l.r;z.s=l.s;const array&lv=l.v;const array&rv=r.v;x;R;}\
A  if(!l.r){\
A   z.r=r.r;z.s=r.s;const array&rv=r.v;array lv=tile(l.v,r.s);x;R;}\
A  if(!r.r){\
A   z.r=l.r;z.s=l.s;array rv=tile(r.v,l.s);const array&lv=l.v;x;R;}\
A  if(l.r!=r.r)err(4);if(l.s!=r.s)err(5);err(99);}
A #define FP(n) NM(n,"",0,0,MT,MFD,DFD,MT,MT);MF(n##_f){n##fn(z,A(),r,p);}
A #define EF(n,m) EXPORT V n##_dwa(lp*z,lp*l,lp*r){try{\
A   A cl,cr,za;if(!isinit){Initfn(za,cl,cr,NULL);isinit=1;}\
A   cpda(cr,r);if(l!=NULL)cpda(cl,l);m##fn(za,cl,cr,env);cpad(z,za);}\
A  catch(U n){derr(n);}\
A  catch(exception e){msg=mkstr(e.what());dmx.e=msg.c_str();derr(500);}}\
A EXPORT V n##_cdf(A*z,A*l,A*r){try{m##fn(*z,*l,*r,env);}catch(U n){derr(n);}\
A  catch(exception x){msg=mkstr(x.what());dmx.e=msg.c_str();derr(500);}}
A
A S FN{STR nm;I sm;I sd;FN(STR nm,I sm,I sd):nm(nm),sm(sm),sd(sd){}
A  FN():nm(""),sm(0),sd(0){}
A  virtual array id(dim4 s){err(16);R array();}
A  virtual V operator()(A&z,const A&r,A*p[]){err(99);}
A  virtual V operator()(A&z,const A&r,D ax,A*p[]){err(99);}
A  virtual V operator()(A&z,const A&l,const A&r,A*p[]){err(99);}
A  virtual V operator()(A&z,const A&l,const A&r,D ax,A*p[]){err(99);}};
A FN MTFN;
A S MOP:FN{FN&ll;A**pp;
A  MOP(STR nm,I sm,I sd,FN&ll,A*pp[]):FN(nm,sm,sd),ll(ll),pp(pp){}};
A S DOP:FN{I fl;I fr;FN&ll;A aa;FN&rr;A ww;A**pp;
A  DOP(STR nm,I sm,I sd,FN&l,FN&r,A*p[])
A   :FN(nm,sm,sd),fl(1),fr(1),ll(l),aa(A()),rr(r),ww(A()),pp(p){}
A  DOP(STR nm,I sm,I sd,A l,FN&r,A*p[])
A   :FN(nm,sm,sd),fl(0),fr(1),ll(MTFN),aa(l),rr(r),ww(A()),pp(p){}
A  DOP(STR nm,I sm,I sd,FN&l,A r,A*p[])
A   :FN(nm,sm,sd),fl(1),fr(0),ll(l),aa(A()),rr(MTFN),ww(r),pp(p){}};
A
```

```
A std::wstring mkstr(const char*s){B c=std::strlen(s);std::wstring t(c,L' ');
A  mbstowcs(&t[0],s,c);R t;}
A I scm(FN&f){R f.sm;}I scm(const A&a){R 1;}
A I scd(FN&f){R f.sd;}I scd(const A&a){R 1;}
A B cnt(dim4 s){B c=1;DO(4,c*=s[i]);R c;}
A B cnt(const A&a){B c=1;DO(a.r,c*=a.s[i]);R c;}
A B cnt(lp*d){B c=1;DO(RANK(d),c*=SHAPE(d)[i]);R c;}
A array scl(I x){R constant(x,dim4(1),s32);}
A A scl(array v){R A(0,dim4(1),v);}
A dtype mxt(dtype at,dtype bt){if(at==c64||bt==c64)R c64;
A  if(at==f64||bt==f64)R f64;
A  if(at==s32||bt==s32)R s32;if(at==s16||bt==s16)R s16;
A  if(at==b8||bt==b8)R b8;err(16);R f64;}
A dtype mxt(const array&a,const array&b){R mxt(a.type(),b.type());}
A dtype mxt(dtype at,const A&b){R mxt(at,b.v.type());}
A Z array da16(B c,dim4 s,lp*d){std::vector<S16>b(c);
A  S8*v=(S8*)DATA(d);DOB(c,b[i]=v[i]);R array(s,b.data());}
A Z array da8(B c,dim4 s,lp*d){std::vector<char>b(c);
A  U8*v=(U8*)DATA(d);DOB(c,b[i]=1&(v[i/8]>>(7-(i%8))))
A  R array(s,b.data());}
A V cpad(lp*d,A&a){I t;B c=cnt(a);
A  switch(a.v.type()){CS(c64,t=APLZ);
A   CS(s32,t=APLI);CS(s16,t=APLSI);CS(b8,t=APLTI);CS(f64,t=APLD);
A   default:if(c)err(16);t=APLI;}
A  B s[4];DO(a.r,s[a.r-(i+1)]=a.s[i]);dwafns->ws->ga(t,a.r,s,d);
A  if(c)a.v.host(DATA(d));}
A V cpda(A&a,lp*d){if(15!=TYPE(d))err(16);if(4<RANK(d))err(16);
A  dim4 s(1);DO(RANK(d),s[RANK(d)-(i+1)]=SHAPE(d)[i]);B c=cnt(d);
A  switch(ETYPE(d)){
A   CS(APLZ,a=A(RANK(d),s,c?array(s,(DZ*)DATA(d)):scl(0)))
A   CS(APLI,a=A(RANK(d),s,c?array(s,(I*)DATA(d)):scl(0)))
A   CS(APLD,a=A(RANK(d),s,c?array(s,(D*)DATA(d)):scl(0)))
A   CS(APLSI,a=A(RANK(d),s,c?array(s,(S16*)DATA(d)):scl(0)))
A   CS(APLTI,a=A(RANK(d),s,c?da16(c,s,d):scl(0)))
A   CS(APLU8,a=A(RANK(d),s,c?da8(c,s,d):scl(0)))
A   default:err(16);}}
A
```

```
A NM(add,"add",1,1,DID,MFD,DFD,MT ,MT )NM(sub,"sub",1,1,DID,MFD,DFD,MT ,MT )
A NM(mul,"mul",1,1,DID,MFD,DFD,MT ,MT )NM(div,"div",1,1,DID,MFD,DFD,MT ,MT )
A NM(max,"max",1,1,DID,MFD,DFD,MT ,MT )NM(min,"min",1,1,DID,MFD,DFD,MT ,MT )
A NM(exp,"exp",1,1,DID,MFD,DFD,MT ,MT )NM(log,"log",1,1,MT ,MFD,DFD,MT ,MT )
A NM(fac,"fac",1,1,DID,MFD,DFD,MT ,MT )NM(res,"res",1,1,DID,MFD,DFD,MT ,MT )
A NM(and,"and",1,1,DID,MT ,DFD,MT ,MT )NM(lor,"lor",1,1,DID,MT ,DFD,MT ,MT )
A NM(lth,"lth",1,1,DID,MT ,DFD,MT ,MT )NM(lte,"lte",1,1,DID,MT ,DFD,MT ,MT )
A NM(gth,"gth",1,1,DID,MT ,DFD,MT ,MT )NM(gte,"gte",1,1,DID,MT ,DFD,MT ,MT )
A NM(eql,"eql",1,1,DID,MT ,DFD,MT ,MT )NM(neq,"neq",1,1,DID,MT ,DFD,MT ,MT )
A NM(nan,"nan",1,1,MT ,MT ,DFD,MT ,MT )NM(nor,"nor",1,1,MT ,MT ,DFD,MT ,MT )
A NM(cir,"cir",1,1,MT ,MFD,DFD,MT ,MT )NM(not,"not",1,0,MT ,MFD,DFD,MT ,MT )
A NM(rot,"rot",0,0,DID,MFD,DFD,MT ,MT )NM(rtf,"rtf",0,0,DID,MFD,DFD,MT ,MT )
A NM(red,"red",0,0,DID,MT ,DFD,MT ,MT )NM(rdf,"rdf",0,0,DID,MT ,DFD,MT ,MT )
A NM(scn,"scn",0,0,DID,MT ,DFD,MT ,MT )NM(scf,"scf",0,0,DID,MT ,DFD,MT ,MT )
A NM(enc,"enc",0,0,DID,MT ,DFD,MT ,MT )NM(dec,"dec",0,0,MT ,MT ,DFD,MT ,MT )
A NM(sqd,"sqd",0,0,MT ,MFD,DFD,MT ,MT )NM(brk,"brk",0,0,MT ,MFD,DFD,MT ,MT )
A NM(iot,"iot",0,0,MT ,MFD,DFD,MT ,MT )NM(rho,"rho",0,0,MT ,MFD,DFD,MT ,MT )
A NM(cat,"cat",0,0,MT ,MFD,DFD,MT ,DAD)NM(ctf,"ctf",0,0,MT ,MFD,DFD,MT ,MT )
A NM(trn,"trn",0,0,MT ,MFD,DFD,MT ,MT )NM(rol,"rol",1,0,MT ,MFD,DFD,MT ,MT )
A NM(dis,"dis",0,0,MT ,MFD,DFD,MT ,MT )NM(par,"par",0,0,MT ,MFD,DFD,MT ,MT )
A NM(eqv,"eqv",0,0,MT ,MFD,DFD,MT ,MT )NM(nqv,"nqv",0,0,MT ,MFD,DFD,MT ,MT )
A NM(rgt,"rgt",0,0,MT ,MFD,DFD,MT ,MT )NM(lft,"lft",0,0,MT ,MFD,DFD,MT ,MT )
A NM(tke,"tke",0,0,MT ,MFD,DFD,MT ,MT )NM(drp,"drp",0,0,MT ,MFD,DFD,MT ,MT )
A NM(unq,"unq",0,0,MT ,MFD,DFD,MT ,MT )NM(int,"int",0,0,MT ,MT ,DFD,MT ,MT )
A NM(gdu,"gdu",0,0,MT ,MFD,DFD,MT ,MT )NM(gdd,"gdd",0,0,MT ,MFD,DFD,MT ,MT )
A NM(mem,"mem",0,0,MT ,MFD,DFD,MT ,MT )NM(fnd,"fnd",0,0,MT ,MT ,DFD,MT ,MT )
A NM(fft,"fft",1,0,MT ,MFD,MT ,MT ,MT )NM(ift,"ift",1,0,MT ,MFD,MT ,MT ,MT )
A NM(mdv,"mdv",1,0,MT ,MFD,DFD,MT ,MT )
A
A ID(add,0,s32)ID(sub,0,s32)ID(mul,1,s32)ID(div,1,s32)ID(res,0,s32)
A ID(min,DBL_MAX,f64)ID(max,-DBL_MAX,f64)ID(exp,1,s32)ID(fac,1,s32)
A ID(and,1,s32)ID(lor,0,s32)ID(lth,0,s32)ID(lte,1,s32)ID(eql,1,s32)
A ID(gth,0,s32)ID(gte,1,s32)ID(neq,0,s32)ID(enc,0,s32)ID(red,1,s32)
A ID(rdf,1,s32)ID(scn,1,s32)ID(scf,1,s32)ID(rot,0,s32)ID(rtf,0,s32)
A
A OD(brk,"brk",scm(l),scd(l),MFD,DFD)
A OM(com,"com",scm(l),scd(l),MFD,DFD)
A OD(dot,"dot",0,0,MT,DFD)
A OD(jot,"jot",(scm(l)&&scm(r)),(scd(l)&&scd(r)),MFD,DFD)
A OM(map,"map",1,1,MFD,DFD)
A OM(oup,"oup",0,0,MT,DFD)
A OD(pow,"pow",scm(l),scd(l),MFD,DFD)
A OM(red,"red",0,0,MFD,DFD)
A OM(rdf,"rdf",0,0,MFD,DFD)
A OD(rnk,"rnk",scm(l),0,MFD,DFD)
A OM(scn,"scn",1,1,MFD,MT)
A OM(scf,"scf",1,1,MFD,MT)
A
```

```
A MF(add_f){z=r;}
A SF(add_f,z.v=lv+rv)
A SF(and_f,if(lv.isbool()&&rv.isbool())z.v=lv&&rv;
A  else if(allTrue<I>(lv>=0&&lv<=1&&rv>0&&rv<=1))z.v=lv&&rv;
A  else{A a(z.r,z.s,lv);A b(z.r,z.s,rv);
A   lorfn(a,a,b,p);z.v=lv*(rv/((!a.v)+a.v));})
A MF(brk_f){err(16);}
A DF(brk_f){if(l.r!=1)err(16);
A  z.r=r.r;z.s=r.s;z.v=l.v(r.v.as(s32));}
A MF(cat_f){z.r=1;z.s[0]=cnt(r);z.v=flat(r.v);}
A DA(cat_f){A nl=l,nr=r;I fx=(I)ceil(ax);
A  if(fx<0||(fx>r.r&&fx>l.r))err(4);
A  if(ax!=fx){if(r.r>3||l.r>3)err(10);
A   if(nl.r){nl.r++;DO(3-fx,nl.s[3-i]=nl.s[3-(i+1)]);nl.s[fx]=1;}
A   if(nr.r){nr.r++;DO(3-fx,nr.s[3-i]=nr.s[3-(i+1)]);nr.s[fx]=1;}
A   if(nl.r)nl.v=moddims(nl.v,nl.s);if(nr.r)nr.v=moddims(nr.v,nr.s);
A   catfn(z,nl,nr,fx,p);R;}
A  if(fx>=r.r&&fx>=l.r)err(4);
A  if(l.r&&r.r&&std::abs((I)l.r-(I)r.r)>1)err(4);
A  z.r=(l.r>=r.r)*l.r+(r.r>l.r)*r.r+(!r.r&&!l.r);
A  dim4 ls=l.s;dim4 rs=r.s;
A  if(!l.r){ls=rs;ls[fx]=1;}if(!r.r){rs=ls;rs[fx]=1;}
A  if(r.r&&l.r>r.r){DO(3-fx,rs[3-i]=rs[3-(i+1)]);rs[fx]=1;}
A  if(l.r&&r.r>l.r){DO(3-fx,ls[3-i]=ls[3-(i+1)]);ls[fx]=1;}
A  DO(4,if(i!=fx&&rs[i]!=ls[i])err(5));
A  DO(4,z.s[i]=(l.r>=r.r||i==fx)*ls[i]+(r.r>l.r||i==fx)*rs[i]);
A  if(!cnt(l)){z.v=r.v;R;}if(!cnt(r)){z.v=l.v;R;}
A  dtype mt=mxt(r.v,l.v);
A  array lv=(l.r?moddims(l.v,ls):tile(l.v,ls)).as(mt);
A  array rv=(r.r?moddims(r.v,rs):tile(r.v,rs)).as(mt);
A  z.v=join(fx,lv,rv);}
A DF(cat_f){if(l.r||r.r){catfn(z,l,r,0,p);R;}
A  A a,b;catfn(a,l,p);catfn(b,r,p);catfn(z,a,b,0,p);}
A MF(cir_f){z.r=r.r;z.s=r.s;z.v=Pi*r.v.as(f64);}
A SF(cir_f,array fv=rv.as(f64);
A  if(!l.r){I x=l.v.as(s32).scalar<I>();if(abs(x)>10)err(16);
A   switch(x){CS(0,z.v=sqrt(1-fv*fv))CS(1,z.v=sin(fv))CS(2,z.v=cos(fv))
A    CS(3,z.v=tan(fv))CS(4,z.v=sqrt(1+fv*fv))CS(5,z.v=sinh(fv))
A    CS(6,z.v=cosh(fv))CS(7,z.v=tanh(fv))CS(8,z.v=sqrt(fv*fv-1))CS(9,z.v=fv)
A    CS(10,z.v=abs(fv))CS(-1,z.v=asin(fv))CS(-2,z.v=acos(fv))
A    CS(-3,z.v=atan(fv))CS(-4,z.v=(fv+1)*sqrt((fv-1)/(fv+1)))
A    CS(-5,z.v=asinh(fv))CS(-6,z.v=acosh(fv))CS(-7,z.v=atanh(fv))
A    CS(-8,z.v=-sqrt(fv*fv-1))CS(-9,z.v=fv)CS(-10,z.v=fv)}R;}
A  if(anyTrue<I>(abs(lv)>10))err(16);B c=cnt(z);std::vector<I> a(c);
A  std::vector<D> b(c);lv.as(s32).host(a.data());fv.host(b.data());
A  std::vector<D> zv(c);
A  DOB(c,switch(a[i]){CS(0,zv[i]=sqrt(1-b[i]*b[i]))CS(1,zv[i]=sin(b[i]))
A   CS(2,zv[i]=cos(b[i]))CS(3,zv[i]=tan(b[i]))CS(4,zv[i]=sqrt(1+b[i]*b[i]))
A   CS(5,zv[i]=sinh(b[i]))CS(6,zv[i]=cosh(b[i]))CS(7,zv[i]=tanh(b[i]))
A   CS(8,zv[i]=sqrt(b[i]*b[i]-1))CS(9,zv[i]=b[i])CS(10,zv[i]=abs(b[i]))
A   CS(-1,zv[i]=asin(b[i]))CS(-2,zv[i]=acos(b[i]))CS(-3,zv[i]=atan(b[i]))
A   CS(-4,zv[i]=(b[i]==-1)?0:(b[i]+1)*sqrt((b[i]-1)/(b[i]+1)))
A   CS(-5,zv[i]=asinh(b[i]))CS(-6,zv[i]=acosh(b[i]))CS(-7,zv[i]=atanh(b[i]))
A   CS(-8,zv[i]=-sqrt(b[i]*b[i]-1))CS(-9,zv[i]=b[i])CS(-10,zv[i]=b[i])})
A  z.v=array(z.s,zv.data());)
A MF(ctf_f){dim4 sp=z.s;sp[1]=r.r?r.s[r.r-1]:1;sp[0]=sp[1]?cnt(r)/sp[1]:1;
A  sp[2]=sp[3]=1;z.r=2;z.s=sp;z.v=!cnt(z)?scl(0):array(r.v,z.s);}
A DF(ctf_f){I x=l.r>r.r?l.r:r.r;if(l.r||r.r){catfn(z,l,r,x-1,p);R;}
A  A a,b;catfn(a,l,p);catfn(b,r,p);catfn(z,a,b,0,p);}
```

```
A DF(dec_f){I ra=r.r?r.r-1:0;I la=l.r?l.r-1:0;z.r=ra+la;z.s=dim4(1);
A  if(l.s[0]!=1&&l.s[0]!=r.s[ra]&&r.s[ra]!=1)err(5);
A  DO(ra,z.s[i]=r.s[i])DO(la,z.s[i+ra]=l.s[i+1])
A  if(!cnt(z)){z.v=scl(0);R;}
A  if(!cnt(r)||!cnt(l)){z.v=constant(0,z.s,s32);R;}
A  B lc=l.s[0];array x=l.v;if(lc==1){lc=r.s[ra];x=tile(x,(I)lc);}
A  x=flip(scan(x,0,AF_BINARY_MUL,false),0);
A  x=array(x,lc,x.elements()/lc).as(f64);
A  array y=array(r.v,cnt(r)/r.s[ra],r.s[ra]).as(f64);
A  z.v=array(matmul(r.s[ra]==1?tile(y,1,(I)l.s[0]):y,x),z.s);}
A MF(dis_f){z.r=0;z.s=eshp;z.v=r.v(0);}
A DF(dis_f){if(l.v.isfloating())err(1);if(l.r>1)err(4);
A  B lc=cnt(l);if(!lc){z=r;R;}if(lc!=1||r.r!=1)err(4);
A  if(allTrue<char>(cnt(r)<=l.v(0)))err(3);
A  z.r=0;z.s=eshp;array i=l.v(0);z.v=r.v(i);}
A MF(div_f){z.r=r.r;z.s=r.s;z.v=1.0/r.v.as(f64);}
A SF(div_f,z.v=lv.as(f64)/rv.as(f64))
A MF(drp_f){if(r.r)err(16);z=r;}
A DF(drp_f){I lv[4];seq it[4];seq ix[4];B c=cnt(l);
A  if(l.r>1||(c>r.r&&r.r))err(4);if(!c){z=r;R;}
A  U rk=r.r?r.r:(U)l.s[0];z.r=rk;z.s=r.s;l.v.as(s32).host(lv);
A  DO((I)c,{U j=rk-(i+1);I a=std::abs(lv[i]);
A   if(a>=r.s[j]){z.s[j]=0;ix[j]=seq(0);it[j]=seq(0);}
A   else if(lv[i]<0){
A    z.s[j]=r.s[j]-a;ix[j]=seq((D)z.s[j]);it[j]=ix[j];}
A   else{z.s[j]=r.s[j]-a;ix[j]=seq(a,(D)r.s[j]-1);it[j]=ix[j]-(D)a;}})
A  if(!cnt(z)){z.v=scl(0);R;}z.v=array(z.s,r.v.type());z.v=0;
A  z.v(it[0],it[1],it[2],it[3])=r.v(ix[0],ix[1],ix[2],ix[3]);}
A DF(enc_f){I rk=r.r+l.r;if(rk>4)err(16);dim4 sp=r.s;DO(l.r,sp[i+r.r]=l.s[i])
A  if(!cnt(sp)){z.r=rk;z.s=sp;z.v=scl(0);R;}dim4 lt=sp,rt=sp;I k=l.r?l.r-1:0;
A  DO(r.r,rt[i]=1)DO(l.r,lt[i+r.r]=1)array rv=tile(r.v,rt);z.r=rk;z.s=sp;
A  array sv=flip(scan(flip(l.v,k),k,AF_BINARY_MUL),k);
A  array lv=tile(array(sv,rt),lt);af::index x[4];x[k]=0;
A  array dv=sv;dv(x[0],x[1],x[2],x[3])=1;I s[]={0,0,0,0};s[k]=-1;
A  dv=shift(dv,s[0],s[1],s[2],s[3]);dv=tile(array(dv,rt),lt);
A  z.v=(lv!=0)*rem(rv,lv)+(lv==0)*rv;z.v=(dv!=0)*(z.v/dv).as(s32);}
A SF(eql_f,z.v=lv==rv)
A MF(eqv_f){z.r=0;z.s=eshp;z.v=scl(r.r!=0);}
A DF(eqv_f){z.r=0;z.s=eshp;
A  if(l.r==r.r&&l.s==r.s){z.v=allTrue(l.v==r.v);R;}z.v=scl(0);}
A MF(exp_f){z.r=r.r;z.s=r.s;z.v=exp(r.v.as(f64));}
A SF(exp_f,z.v=pow(lv.as(f64),rv.as(f64)))
A MF(fac_f){z.r=r.r;z.s=r.s;z.v=factorial(r.v.as(f64));}
A SF(fac_f,array lvf=lv.as(f64);array rvf=rv.as(f64);
A  z.v=exp(log(tgamma(lvf))+log(tgamma(rvf))-log(tgamma(lvf+rvf))))
A MF(fft_f){z.r=r.r;z.s=r.s;z.v=dft(r.v.type()==c64?r.v:r.v.as(c64),1,r.s);}
A MF(ift_f){z.r=r.r;z.s=r.s;z.v=idft(r.v.type()==c64?r.v:r.v.as(c64),1,r.s);}
A DF(fnd_f){A t(r.r,r.s,array(r.s,b8));if(!cnt(t)){t.v=scl(0);z=t;R;}
A  t.v=0;if(l.r>r.r){z=t;R;}DO(4,if(l.s[i]>r.s[i]){z=t;R;})
A  if(!cnt(l)){t.v=1;z=t;R;}dim4 sp;DO(4,sp[i]=1+(t.s[i]-l.s[i]))
A  seq x[4];DO(4,x[i]=seq((D)sp[i]))t.v(x[0],x[1],x[2],x[3])=1;
A  DO((I)l.s[0],I m=i;
A   DO((I)l.s[1],I k=i;
A    DO((I)l.s[2],I j=i;
A     DO((I)l.s[3],t.v(x[0],x[1],x[2],x[3])=t.v(x[0],x[1],x[2],x[3])
A      &(tile(l.v(m,k,j,i),sp)
A       ==r.v(x[0]+(D)m,x[1]+(D)k,x[2]+(D)j,x[3]+(D)i))))))
A  z=t;}
A
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A MF(gdd_f){if(r.r<1)err(4);z.r=1;z.s=dim4(r.s[r.r-1]);
A  if(!cnt(r)){z.v=r.v;R;}I c=1;DO(r.r-1,c*=(I)r.s[i]);
A  array mt,a=array(r.v,c,r.s[r.r-1]);z.v=iota(z.s,dim4(1),s32);
A  DO(c,sort(mt,z.v,flat(a(c-(i+1),z.v)),z.v,0,false))}
A DF(gdd_f){err(16);}
A MF(gdu_f){if(r.r<1)err(4);z.r=1;z.s=dim4(r.s[r.r-1]);
A  if(!cnt(r)){z.v=r.v;R;}I c=1;DO(r.r-1,c*=(I)r.s[i]);
A  array mt,a=array(r.v,c,r.s[r.r-1]);z.v=iota(z.s,dim4(1),s32);
A  DO(c,sort(mt,z.v,flat(a(c-(i+1),z.v)),z.v,0,true))}
A DF(gdu_f){err(16);}
A SF(gte_f,z.v=lv>=rv)
A SF(gth_f,z.v=lv>rv)
A DF(int_f){if(r.r>1||l.r>1)err(4);
A  if(!cnt(r)||!cnt(l)){z.v=scl(0);z.s=dim4(0);z.r=1;R;}
A  dtype mt=mxt(l.v,r.v);z.v=setIntersect(l.v.as(mt),r.v.as(mt));
A  z.r=1;z.s=dim4(z.v.elements());}
A MF(iot_f){if(r.r>1)err(4);B c=cnt(r);if(c>4)err(10);
A  if(c>1)err(16);
A  z.r=1;z.s=dim4(r.v.as(s32).scalar<I>());
A  z.v=z.s[0]?iota(z.s,dim4(1),s32):scl(0);}
A DF(iot_f){z.r=r.r;z.s=r.s;B c=cnt(r);if(!c){z.v=scl(0);R;}
A  B lc=cnt(l)+1;if(lc==1){z.v=scl(0);R;};if(l.r>1)err(16);
A  array rf=flat(r.v).T();dtype mt=mxt(l.v,rf);
A  z.v=join(0,tile(l.v,1,(U)c).as(mt),rf.as(mt))==tile(rf,(U)lc,1);
A  z.v=min((z.v*iota(dim4(lc),dim4(1,c),s32)+((!z.v)*lc).as(s32)),0);
A  z.v=array(z.v,z.s);}
A MF(lft_f){z=r;}
A DF(lft_f){z=l;}
A MF(log_f){z.r=r.r;z.s=r.s;z.v=log(r.v.as(f64));}
A SF(log_f,z.v=log(rv.as(f64))/log(lv.as(f64)))
A SF(lor_f,if(rv.isbool()&&lv.isbool())z.v=lv||rv;
A  else if(lv.isbool()&&rv.isinteger())z.v=lv+(!lv)*abs(rv).as(rv.type());
A  else if(rv.isbool()&&lv.isinteger())z.v=rv+(!rv)*abs(lv).as(lv.type());
A  else if(lv.isinteger()&&rv.isinteger()){B c=cnt(z);
A   std::vector<I> a(c);abs(lv).as(s32).host(a.data());
A   std::vector<I> b(c);abs(rv).as(s32).host(b.data());
A   DOB(c,while(b[i]){I t=b[i];b[i]=a[i]%b[i];a[i]=t;})
A   z.v=array(z.s,a.data());}
A  else{B c=cnt(z);
A   std::vector<D> a(c);abs(lv).as(f64).host(a.data());
A   std::vector<D> b(c);abs(rv).as(f64).host(b.data());
A   DOB(c,while(b[i]>1e-12){D t=b[i];b[i]=fmod(a[i],b[i]);a[i]=t;})
A   z.v=array(z.s,a.data());})
A SF(lte_f,z.v=lv<=rv)
A SF(lth_f,z.v=lv<rv)
A MF(max_f){z.r=r.r;z.s=r.s;z.v=ceil(r.v).as(r.v.type());}
A SF(max_f,z.v=max(lv,rv))
A MF(mem_f){z.r=1;z.s=dim4(cnt(r));z.v=flat(r.v);}
A DF(mem_f){z.r=l.r;z.s=l.s;I lc=(I)cnt(z);if(!lc){z.v=scl(0);R;}
A  if(!cnt(r)){z.v=array(z.s,b8);z.v=0;R;}
A  array y=setUnique(flat(r.v));I rc=(I)y.elements();
A  array x=array(flat(l.v),lc,1);y=array(y,1,rc);
A  z.v=array(anyTrue(tile(x,1,rc)==tile(y,lc,1),1),z.s);}
A MF(mdv_f){if(r.r>2)err(4);if(r.r==2&&r.s[1]<r.s[0])err(5);if(!cnt(r))err(5);
A  if(r.s[0]==r.s[1]){z.r=r.r;z.s=r.s;z.v=inverse(r.v);R;}
A  if(r.r==1){z.v=matmulNT(inverse(matmulTN(r.v,r.v)),r.v);z.r=r.r;z.s=r.s;R;}
A  z.v=matmulTN(inverse(matmulNT(r.v,r.v)),r.v);z.r=r.r;z.s=r.s;
A  B k=z.s[0];z.s[0]=z.s[1];z.s[1]=k;z.v=transpose(z.v);}
A
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A DF(mdv_f){if(r.r>2)err(4);if(l.r>2)err(4);if(r.r==2&&r.s[1]<r.s[0])err(5);
A  if(!cnt(r)||!cnt(l))err(5);if(r.r&&l.r&&l.s[l.r-1]!=r.s[r.r-1])err(5);
A  array rv=r.v,lv=l.v;if(r.r==1)rv=transpose(rv);if(l.r==1)lv=transpose(lv);
A  z.v=transpose(matmul(inverse(matmulNT(rv,rv)),matmulNT(rv,lv)));
A  z.r=(l.r-(l.r>0))+(r.r-(r.r>0));
A  if(l.r>1)z.s[0]=l.s[0];if(r.r>1)z.s[l.r>1]=r.s[0];}
A MF(min_f){z.r=r.r;z.s=r.s;z.v=floor(r.v).as(r.v.type());}
A SF(min_f,z.v=min(lv,rv))
A MF(mul_f){z.r=r.r;z.s=r.s;z.v=(r.v>0)-(r.v<0);}
A SF(mul_f,z.v=lv*rv)
A SF(nan_f,z.v=!(lv&&rv))
A SF(neq_f,z.v=lv!=rv)
A SF(nor_f,z.v=!(lv||rv))
A MF(not_f){z.r=r.r;z.s=r.s;z.v=!r.v;}
A DF(not_f){err(16);}
A MF(nqv_f){z.v=scl(r.r?(I)r.s[r.r-1]:1);z.r=0;z.s=dim4(1);}
A DF(nqv_f){z.r=0;z.s=eshp;I t=l.r==r.r&&l.s==r.s;
A  if(t)t=allTrue<I>(l.v==r.v);z.v=scl(!t);}
A MF(par_f){err(16);}
A DF(par_f){err(16);}
A DF(red_f){if(l.r>1)err(4);z.r=r.r?r.r:1;z.s=r.s;
A  if(l.r!=0&&l.s[0]!=1&&r.r!=0&&r.s[0]!=1&&l.s[0]!=r.s[0])err(5);
A  array x=l.v;if(cnt(l)==1)x=tile(x,(I)r.s[0]);
A  array y=r.v;if(r.s[0]==1)y=tile(y,(I)cnt(l));
A  z.s[0]=sum<B>(abs(x));if(!cnt(z)){z.v=scl(0);R;}
A  array w=where(x).as(s32);
A  if(z.s[0]==w.elements()){z.v=y(w,span);R;}
A  array i=shift(accum(abs(x(w))),1),d=shift(w,1);i(0)=0;d(0)=0;
A  array v=array(z.s[0],s32),u=array(z.s[0],s32);v=0;u=0;
A  array s=(!sign(x(w))).as(s32);array t=shift(s,1);t(0)=0;
A  v(i)=w-d;u(i)=s-t;z.v=y(accum(v),span);
A  z.v*=tile(accum(u),1,(I)z.s[1],(I)z.s[2],(I)z.s[3]);}
A MF(res_f){z.r=r.r;z.s=r.s;z.v=abs(r.v).as(r.v.type());}
A SF(res_f,z.v=rv-lv*floor(rv.as(f64)/(lv+(0==lv))))
A DF(rdf_f){if(l.r>1)err(4);I ra=r.r?r.r-1:0;z.r=ra+1;z.s=r.s;
A  if(l.r!=0&&l.s[0]!=1&&r.r!=0&&r.s[ra]!=1&&l.s[0]!=r.s[ra])err(5);
A  array x=l.v;array y=r.v;if(cnt(l)==1)x=tile(x,(I)r.s[ra]);
A  if(r.s[ra]==1){dim4 s(1);s[ra]=cnt(l);y=tile(y,s);}
A  z.s[ra]=sum<B>(abs(x));if(!cnt(z)){z.v=scl(0);R;}
A  array w=where(x).as(s32);af::index ix[4];if(z.s[ra]==w.elements()){
A   ix[ra]=w;z.v=y(ix[0],ix[1],ix[2],ix[3]);R;}
A  array i=shift(accum(abs(x(w))),1),d=shift(w,1);i(0)=0;d(0)=0;
A  array v=array(z.s[ra],s32),u=array(z.s[ra],s32);v=0;u=0;
A  array s=(!sign(x(w))).as(s32);array t=shift(s,1);t(0)=0;
A  v(i)=w-d;u(i)=s-t;ix[ra]=accum(v);z.v=y(ix[0],ix[1],ix[2],ix[3]);
A  dim4 s1(1),s2(z.s);s1[ra]=z.s[ra];s2[ra]=1;u=array(accum(u),s1);
A  z.v*=tile(u,(I)s2[0],(I)s2[1],(I)s2[2],(I)s2[3]);}
A MF(rgt_f){z=r;}
A DF(rgt_f){z=r;}
A MF(rho_f){I sp[4]={1,1,1,1};DO(r.r,sp[r.r-(i+1)]=(I)r.s[i]);
A  z.s=dim4(r.r);z.r=1;if(!cnt(z)){z.v=scl(0);R;}z.v=array(z.s,sp);}
A DF(rho_f){B cr=cnt(r);B cl=cnt(l);B s[4];if(l.r>1)err(11);if(cl>4)err(16);
A  l.v.as(s64).host(s);z.r=(I)cl;DO(4,z.s[i]=i>=z.r?1:s[z.r-(i+1)])B cz=cnt(z);
A  if(!cz){z.v=scl(0);R;}z.v=array(cz==cr?r.v:flat(r.v)(iota(cz)%cr),z.s);}
A MF(rol_f){z.r=r.r;z.s=r.s;if(!cnt(r)){z.v=r.v;R;}
A  array rnd=randu(r.v.dims(),f64);z.v=(0==r.v)*rnd+trunc(r.v*rnd);}
A
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A DF(rol_f){if(cnt(r)!=1||cnt(l)!=1)err(5);
A  D lv=l.v.as(f64).scalar<D>();D rv=r.v.as(f64).scalar<D>();
A  if(lv>rv||lv!=floor(lv)||rv!=floor(rv)||lv<0||rv<0)err(11);
A  I s=(I)lv;I t=(I)rv;z.r=1;z.s=dim4(s);if(!s){z.v=scl(0);R;}
A  std::vector<I> g(t);std::vector<I> d(t);
A  ((1+range(t))*randu(t)).as(s32).host(g.data());
A  DO(t,I j=g[i];if(i!=j)d[i]=d[j];d[j]=i)z.v=array(z.s,d.data());}
A MF(rot_f){z.r=r.r;z.s=r.s;z.v=flip(r.v,0);}
A DF(rot_f){I lc=(I)cnt(l);if(lc==1){z.r=r.r;z.s=r.s;
A   z.v=shift(r.v,-l.v.as(s32).scalar<I>());R;}
A  if(l.r!=r.r-1)err(5);DO(l.r,if(l.s[i]!=r.s[i+1])err(5))
A  std::vector<I> x(lc);l.v.as(s32).host(x.data());
A  z.v=array(r.v,r.s[0],lc);z.r=r.r;z.s=r.s;
A  DO(lc,z.v(span,i)=shift(z.v(span,i),-x[i]))z.v=array(z.v,z.s);}
A MF(rtf_f){z.r=r.r;z.s=r.s;z.v=r.r?flip(r.v,r.r-1):r.v;}
A DF(rtf_f){I lc=(I)cnt(l);I ra=r.r?r.r-1:0;I ix[]={0,0,0,0};
A  if(lc==1){z.r=r.r;z.s=r.s;ix[ra]=-l.v.as(s32).scalar<I>();
A   z.v=shift(r.v,ix[0],ix[1],ix[2],ix[3]);R;}
A  if(l.r!=r.r-1)err(5);DO(l.r,if(l.s[i]!=r.s[i])err(5))
A  std::vector<I> x(lc);l.v.as(s32).host(x.data());
A  z.v=array(r.v,lc,r.s[ra]);z.r=r.r;z.s=r.s;
A  DO(lc,z.v(i,span)=shift(z.v(i,span),0,-x[i]))
A  z.v=array(z.v,z.s);}
A DF(scn_f){if(r.s[0]!=1&&r.s[0]!=sum<I>(l.v>0))err(5);
A  if(l.r>1)err(5);array ca=max(1,abs(l.v)).as(s32);I c=sum<I>(ca);
A  if(!cnt(l))c=0;A t(r.r?r.r:1,r.s,scl(0));t.s[0]=c;
A  if(!cnt(t)){z=t;R;}t.v=array(t.s,r.v.type());t.v=0;
A  array pw=0<l.v;array pa=pw*l.v;I pc=sum<I>(pa);if(!pc){z=t;R;}
A  pw=where(pw);pa=scan(pa(pw),0,AF_BINARY_ADD,false);
A  array si(pc,s32);si=0;si(pa)=1;si=accum(si)-1;
A  array ti(pc,s32);ti=1;ti(pa)=scan(ca,0,AF_BINARY_ADD,false)(pw);
A  ti=scanByKey(si,ti);t.v(ti,span)=r.v(si,span);z=t;}
A DF(scf_f){I ra=r.r?r.r-1:0;af::index sx[4];af::index tx[4];
A  if(r.s[ra]!=1&&r.s[ra]!=sum<I>(l.v>0))err(5);
A  if(l.r>1)err(5);array ca=max(1,abs(l.v)).as(s32);I c=sum<I>(ca);
A  if(!cnt(l))c=0;A t(ra+1,r.s,scl(0));t.s[ra]=c;
A  if(!cnt(t)){z=t;R;}t.v=array(t.s,r.v.type());t.v=0;
A  array pw=0<l.v;array pa=pw*l.v;I pc=sum<I>(pa);if(!pc){z=t;R;}
A  pw=where(pw);pa=scan(pa(pw),0,AF_BINARY_ADD,false);
A  array si(pc,s32);si=0;si(pa)=1;si=accum(si)-1;sx[ra]=si;
A  array ti(pc,s32);ti=1;ti(pa)=scan(ca,0,AF_BINARY_ADD,false)(pw);
A  ti=scanByKey(si,ti);tx[ra]=ti;
A  t.v(tx[0],tx[1],tx[2],tx[3])=r.v(sx[0],sx[1],sx[2],sx[3]);z=t;}
A MF(sqd_f){z=r;}
A DF(sqd_f){if(l.r>1)err(4);B s=!l.r?1:l.s[l.r-1];
A  if(s>r.r)err(5);if(!cnt(l)){z=r;R;}
A  I sv[4];af::index x[4];l.v.as(s32).host(sv);
A  DO((I)s,if(sv[i]<0||sv[i]>=r.s[i])err(3));
A  DO((I)s,x[r.r-(i+1)]=sv[i]);z.r=r.r-(U)s;z.s=dim4(z.r,r.s.get());
A  z.v=r.v(x[0],x[1],x[2],x[3]);}
A MF(sub_f){z.r=r.r;z.s=r.s;z.v=-r.v;}
A SF(sub_f,z.v=lv-rv)
A MF(tke_f){z=r;}
A
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A DF(tke_f){I lv[4];seq it[4];seq ix[4];B c=cnt(l);
A  if(l.r>1||(c>r.r&&r.r))err(4);if(!c){z=r;R;}
A  U rk=r.r?r.r:(U)l.s[0];z.r=rk;z.s=r.s;l.v.as(s32).host(lv);
A  DO((I)c,{U j=rk-(i+1);I a=std::abs(lv[i]);z.s[j]=a;
A   if(a>r.s[j])ix[j]=seq((D)r.s[j]);
A   else if(lv[i]<0)ix[j]=seq((D)r.s[j]-a,(D)r.s[j]-1);
A   else ix[j]=seq(a);
A   it[j]=ix[j]+(lv[i]<0)*(a-(D)r.s[j]);})
A  if(!cnt(z)){z.v=scl(0);R;}z.v=array(z.s,r.v.type());z.v=0;
A  z.v(it[0],it[1],it[2],it[3])=r.v(ix[0],ix[1],ix[2],ix[3]);}
A MF(trn_f){z.r=r.r;DO(r.r,z.s[i]=r.s[r.r-(i+1)])
A  switch(r.r){CS(0,z.v=r.v)CS(1,z.v=r.v)CS(2,z.v=r.v.T())
A   CS(3,z.v=reorder(r.v,2,1,0))CS(4,z.v=reorder(r.v,3,2,1,0))}}
A DF(trn_f){I lv[4];if(l.r>1||cnt(l)!=r.r)err(5);
A  l.v.as(s32).host(lv);DO(r.r,if(lv[i]<0||lv[i]>=r.r)err(4))
A  U8 f[]={0,0,0,0};DO(r.r,f[lv[i]]=1)
A  U8 t=1;DO(r.r,if(t&&!f[i])t=0;else if(!t&&f[i])err(5))
A  DO(r.r,if(!f[i])err(16))
A  z.r=r.r;DO(r.r,z.s[r.r-(lv[i]+1)]=r.s[r.r-(i+1)])
A  I s[4];DO(r.r,s[r.r-(lv[i]+1)]=r.r-(i+1))
A  switch(r.r){CS(0,z.v=r.v)CS(1,z.v=r.v)
A   CS(2,z.v=reorder(r.v,s[0],s[1]))
A   CS(3,z.v=reorder(r.v,s[0],s[1],s[2]))
A   CS(4,z.v=reorder(r.v,s[0],s[1],s[2],s[3]))}}
A MF(unq_f){if(r.r>1)err(4);z.r=1;if(!cnt(r)){z.s=r.s;z.v=r.v;R;}
A  array a,b;sort(a,b,r.v);z.v=a!=shift(a,1);z.v(0)=1;
A  z.v=where(z.v);sort(b,z.v,b(z.v),a(z.v));
A  z.s=dim4(z.v.elements());}
A DF(unq_f){if(r.r>1||l.r>1)err(4);z.r=1;dtype mt=mxt(l.v,r.v);
A  if(!cnt(l)){z.s=r.s;z.v=r.v;R;}if(!cnt(r)){z.s=l.s;z.v=l.v;R;}
A  array x=setUnique(l.v);B c=x.elements();
A  z.v=!anyTrue(tile(r.v,1,(U)c)==tile(array(x,1,c),(U)r.s[0],1),1);
A  z.v=join(0,l.v.as(mt),r.v(where(z.v)).as(mt));
A  z.s=dim4(z.v.elements());}
A
```

```
A #define brkop(zz,ll,rr,pp) brk_o zz(ll,rr,pp)
A #define comop(zz,rr,pp) com_o zz(rr,pp)
A #define dotop(zz,ll,rr,pp) dot_o zz(ll,rr,pp)
A #define mapop(zz,rr,pp) map_o zz(rr,pp)
A #define redop(zz,rr,pp) red_o zz(rr,pp)
A #define jotop(zz,ll,rr,pp) jot_o zz(ll,rr,pp)
A #define oupop(zz,rr,pp) oup_o zz(rr,pp)
A #define powop(zz,ll,rr,pp) pow_o zz(ll,rr,pp)
A #define rdfop(zz,rr,pp) rdf_o zz(rr,pp)
A #define rnkop(zz,ll,rr,pp) rnk_o zz(ll,rr,pp)
A #define scnop(zz,rr,pp) scn_o zz(rr,pp)
A #define scfop(zz,rr,pp) scf_o zz(rr,pp)
A
A MF(brk_o){ll(z,r,(r.r?r.r-1:0)-ww.v.as(f64).scalar<D>(),p);}
A DF(brk_o){D ax=l.r;if(r.r>l.r)ax=r.r;if(ax)ax--;
A  ll(z,l,r,ax-ww.v.as(f64).scalar<D>(),p);}
A MF(com_o){ll(z,r,r,p);}DF(com_o){ll(z,r,l,p);}
A DF(dot_o){I ra=r.r?r.r-1:0;if(r.r&&l.r&&l.s[0]!=r.s[ra])err(5);
A  I la=l.r?l.r-1:0;A t(la+ra,r.s,r.v(0));if(t.r>4)err(10);
A  t.s[ra]=1;DO(la,t.s[i+ra]=l.s[i+1])if(!cnt(t)){t.v=scl(0);z=t;R;}
A  if(!l.s[0]||!r.s[ra]){t.v=ll.id(t.s);z=t;R;}
A  I c=(I)(l.r?l.s[0]:r.s[ra]);
A  I rc=(I)(cnt(r)/r.s[ra]);I lc=(I)(cnt(l)/l.s[0]);
A  array x=array(l.v,(I)l.s[0],lc);array y=array(r.v,rc,(I)r.s[ra]);
A  if(1==l.s[0]){x=tile(x,c,1);}if(1==r.s[ra]){y=tile(y,1,c);}
A  if("add"==ll.nm&&"mul"==rr.nm){
A   t.v=array(matmul(y.as(f64),x.as(f64)),t.s);z=t;R;}
A  x=tile(array(x,c,1,lc),1,rc,1);y=tile(y.T(),1,1,lc);
A  A X(3,dim4(c,rc,lc),x.as(f64));A Y(3,dim4(c,rc,lc),y.as(f64));
A  mapop(mfn,rr,p);redop(rfn,ll,p);mfn(X,X,Y,p);rfn(X,X,p);
A  t.v=array(X.v,t.s);z=t;}
A MF(jot_o){if(!fl){rr(z,aa,r,p);R;}if(!fr){ll(z,r,ww,p);R;}
A  rr(z,r,p);ll(z,z,p);}
A DF(jot_o){if(!fl||!fr){err(2);}rr(z,r,p);ll(z,l,z,p);}
A MF(map_o){if(scm(ll)){ll(z,r,p);R;}
A  z.r=r.r;z.s=r.s;I c=(I)cnt(z);if(!c){z.v=scl(0);R;}
A  A zs;A rs=scl(r.v(0));ll(zs,rs,p);if(c==1){z.v=zs.v;R;}
A  array v=array(z.s,zs.v.type());v(0)=zs.v(0);
A  DO(c-1,rs.v=r.v(i+1);ll(zs,rs,p);v(i+1)=zs.v(0))z.v=v;}
A DF(map_o){if(scd(ll)){ll(z,l,r,p);R;}
A  if((l.r==r.r&&l.s==r.s)||!l.r){z.r=r.r;z.s=r.s;}
A  else if(!r.r){z.r=l.r;z.s=l.s;}else if(l.r!=r.r)err(4);
A  else if(l.s!=r.s)err(5);else err(99);I c=(I)cnt(z);
A  if(!c){z.v=scl(0);R;}A zs;A rs=scl(r.v(0));A ls=scl(l.v(0));
A  ll(zs,ls,rs,p);if(c==1){z.v=zs.v;R;}
A  array v=array(z.s,zs.v.type());v(0)=zs.v(0);
A  if(!r.r){rs.v=r.v;
A   DO(c-1,ls.v=l.v(i+1);ll(zs,ls,rs,p);v(i+1)=zs.v(0);)
A   z.v=v;R;}
A  if(!l.r){ls.v=l.v;
A   DO(c-1,rs.v=r.v(i+1);ll(zs,ls,rs,p);v(i+1)=zs.v(0);)
A   z.v=v;R;}
A  DO(c-1,ls.v=l.v(i+1);rs.v=r.v(i+1);ll(zs,ls,rs,p);
A   v(i+1)=zs.v(0))z.v=v;}
A DF(oup_o){A t(l.r+r.r,r.s,r.v(0));if(t.r>4)err(10);
A  DO(l.r,t.s[i+r.r]=l.s[i])if(!cnt(t)){t.v=scl(0);z=t;R;}
A  array x(flat(l.v),1,cnt(l));array y(flat(r.v),cnt(r),1);
A  dim4 ts(cnt(r),cnt(l));x=tile(x,(I)ts[0],1);y=tile(y,1,(I)ts[1]);
A  mapop(mfn,ll,p);A xa(2,ts,x);A ya(2,ts,y);mfn(xa,xa,ya,p);
A  t.v=array(xa.v,t.s);z=t;}
```

```
A MF(pow_o){if(fr){A t;A v=r;
A   do{A u;ll(u,v,p);rr(t,u,v,p);if(t.r)err(5);v=u;}
A   while(!t.v.as(s32).scalar<I>());z=v;R;}
A  if(ww.r)err(4);I c=ww.v.as(s32).scalar<I>();z=r;DO(c,ll(z,z,p))}
A DF(pow_o){if(fr){A t;A v=r;
A   do{A u;ll(u,l,v,p);rr(t,u,v,p);if(t.r)err(5);v=u;}
A   while(!t.v.as(s32).scalar<I>());z=v;R;}
A  if(ww.r)err(4);I c=ww.v.as(s32).scalar<I>();
A  A t=r;DO(c,ll(t,l,t,p))z=t;}
A MF(rdf_o){A t(r.r?r.r-1:0,dim4(1),r.v(0));DO(t.r,t.s[i]=r.s[i])
A  I rc=(I)r.s[t.r];I zc=(I)cnt(t);mapop(mfn,ll,p);
A  if(!zc){t.v=scl(0);z=t;R;}if(!rc){t.v=ll.id(t.s);z=t;R;}
A  if(1==rc){t.v=array(r.v,t.s);z=t;R;}
A  if("add"==ll.nm){if(r.v.isbool())t.v=count(r.v,t.r).as(s32);
A   else t.v=sum(r.v.as(f64),t.r);z=t;R;}
A  if("mul"==ll.nm){t.v=product(r.v.as(f64),t.r);z=t;R;}
A  if("min"==ll.nm){t.v=min(r.v,t.r);z=t;R;}
A  if("max"==ll.nm){t.v=max(r.v,t.r);z=t;R;}
A  if("and"==ll.nm){t.v=allTrue(r.v,t.r);z=t;R;}
A  if("lor"==ll.nm){t.v=anyTrue(r.v,t.r);z=t;R;}
A  af::index x[4];x[t.r]=rc-1;t.v=r.v(x[0],x[1],x[2],x[3]);
A  DO(rc-1,x[t.r]=rc-(i+2);
A   mfn(t,A(t.r,t.s,r.v(x[0],x[1],x[2],x[3])),t,p));z=t;}
A DF(rdf_o){if(l.r!=0&&(l.r!=1||l.s[0]!=1))err(5);if(!r.r)err(4);
A  I lv=l.v.as(s32).scalar<I>();I ra=r.r-1;
A   if((r.s[ra]+1)<lv)err(5);I rc=(I)((1+r.s[ra])-abs(lv));
A  mapop(mfn,ll,p);A t(r.r,r.s,scl(0));t.s[ra]=rc;if(!cnt(t)){z=t;R;}
A  if(!lv){t.v=ll.id(t.s);z=t;R;}seq rng(rc);af::index x[4];
A  if(lv>=0){x[ra]=rng+((D)lv-1);t.v=r.v(x[0],x[1],x[2],x[3]);
A   DO(lv-1,x[ra]=rng+((D)lv-(i+2));
A    mfn(t,A(t.r,t.s,r.v(x[0],x[1],x[2],x[3])),t,p))
A  }else{x[ra]=rng;t.v=r.v(x[0],x[1],x[2],x[3]);
A   DO(abs(lv)-1,x[ra]=rng+(D)(i+1);
A    mfn(t,A(t.r,t.s,r.v(x[0],x[1],x[2],x[3])),t,p))}
A  z=t;}
A MF(red_o){A t(r.r?r.r-1:0,dim4(1),z.v);DO(t.r,t.s[i]=r.s[i+1])
A  I rc=(I)r.s[0];I zc=(I)cnt(t);if(!zc){t.v=scl(0);z=t;R;}
A  if(!rc){t.v=ll.id(t.s);z=t;R;}
A  if(1==rc){t.v=array(r.v,t.s);z=t;R;}
A  if("add"==ll.nm){if(r.v.isbool())t.v=count(r.v,0).as(s32);
A   else t.v=sum(r.v.as(f64),0);z=t;R;}
A  if("mul"==ll.nm){t.v=product(r.v.as(f64),0);z=t;R;}
A  if("min"==ll.nm){t.v=min(r.v,0);z=t;R;}
A  if("max"==ll.nm){t.v=max(r.v,0);z=t;R;}
A  if("and"==ll.nm){t.v=allTrue(r.v,0);z=t;R;}
A  if("lor"==ll.nm){t.v=anyTrue(r.v,0);z=t;R;}
A  t.v=r.v(rc-1,span);mapop(mfn,ll,p);
A  DO(rc-1,mfn(t,A(t.r,t.s,r.v(rc-(i+2),span)),t,p))z=t;}
A DF(red_o){if(l.r!=0&&(l.r!=1||l.s[0]!=1))err(5);if(!r.r)err(4);
A  I lv=l.v.as(s32).scalar<I>();if((r.s[0]+1)<lv)err(5);
A  I rc=(I)((1+r.s[0])-abs(lv));mapop(mfn,ll,p);
A  A t(r.r,r.s,scl(0));t.s[0]=rc;if(!cnt(t)){z=t;R;}
A  if(!lv){t.v=ll.id(t.s);z=t;R;}seq rng(rc);
A  if(lv>=0){t.v=r.v(rng+((D)lv-1),span);
A   DO(lv-1,mfn(t,A(t.r,t.s,r.v(rng+((D)lv-(i+2)),span)),t,p))
A  }else{t.v=r.v(rng,span);
A   DO(abs(lv)-1,mfn(t,A(t.r,t.s,r.v(rng+(D)(i+1),span)),t,p))}
A  z=t;}
A
```

```
A MF(rnk_o){if(cnt(ww)!=1)err(4);I cr=ww.v.as(s32).scalar<I>();
A  if(scm(ll)||cr>=r.r){ll(z,r,p);R;}
A  if(cr<=-r.r||!cr){mapop(f,ll,p);f(z,r,p);R;}
A  if(cr<0)cr=r.r+cr;if(cr>3)err(10);I dr=r.r-cr;
A  dim4 sp(1);DO(dr,sp[cr]*=r.s[i+cr])DO(cr,sp[i]=r.s[i])
A  std::vector<A> tv(sp[cr]);A b(cr+1,sp,array(r.v,sp));
A  DO((I)sp[cr],sqdfn(tv[i],scl(scl(i)),b,p);ll(tv[i],tv[i],p))
A  I mr=0;dim4 ms(1);dtype mt=b8;if(mr>3)err(10);
A  DO((I)sp[cr],if(mr<tv[i].r)mr=tv[i].r;mt=mxt(mt,tv[i]);I si=i;
A   DO(4,if(ms[3-i]<tv[si].s[3-i]){ms=tv[si].s;break;}))
A  I mc=(I)cnt(ms);array v(mc*sp[cr],mt);v=0;
A  DO((I)sp[cr],seq ix((D)cnt(tv[i]));v(ix+(D)(i*mc))=flat(tv[i].v))
A  z.r=mr+dr;z.s=ms;z.s[mr]=sp[cr];z.v=array(v,z.s);}
A DF(rnk_o){I cl,cr,dl,dr;dim4 sl(1),sr(1);array wwv=ww.v.as(s32);
A  if(cnt(ww)==1)cl=cr=wwv.scalar<I>();
A  else if(cnt(ww)==2){cl=wwv.scalar<I>();cr=wwv(1).scalar<I>();}
A  else err(4);
A  if(cl>l.r)cl=l.r;if(cr>r.r)cr=r.r;if(cl<-l.r)cl=0;if(cr<-r.r)cr=0;
A  if(cl<0)cl=l.r+cl;if(cr<0)cr=r.r+cr;if(cr>3||cl>3)err(10);
A  dl=l.r-cl;dr=r.r-cr;if(dl!=dr&&dl&&dr)err(4);
A  if(dl==dr)DO(dr,if(l.s[i+cl]!=r.s[i+cr])err(5))
A  DO(dl,sl[cl]*=l.s[i+cl])DO(cl,sl[i]=l.s[i])
A  DO(dr,sr[cr]*=r.s[i+cr])DO(cr,sr[i]=r.s[i])
A  B sz=dl>dr?sl[cl]:sr[cr];std::vector<A> tv(sz);
A  A a(cl+1,sl,array(l.v,sl));A b(cr+1,sr,array(r.v,sr));
A  I mr=0;dim4 ms(1);dtype mt=b8;
A  DO((I)sz,A ta;A tb;A ai=scl(scl(i%sl[cl]));A bi=scl(scl(i%sr[cr]));
A   sqdfn(ta,ai,a,p);sqdfn(tb,bi,b,p);ll(tv[i],ta,tb,p);
A   if(mr<tv[i].r)mr=tv[i].r;mt=mxt(mt,tv[i]);A t=tv[i];
A   DO(4,if(ms[i]<t.s[i])ms[i]=t.s[i]))
A  B mc=cnt(ms);array v(mc*sz,mt);v=0;
A  DOB(sz,seq ix((D)cnt(tv[i]));v(ix+(D)(i*mc))=flat(tv[i].v))
A  z.r=mr+(dr>dl?dr:dl);z.s=ms;z.s[mr]=sz;z.v=array(v,z.s);}
A MF(scn_o){z.r=r.r;z.s=r.s;I rc=(I)r.s[0];
A  if(1==rc){z.v=r.v;R;}if(!cnt(z)){z.v=scl(0);R;}
A  if("add"==ll.nm){z.v=scan(r.v.as(f64),0,AF_BINARY_ADD);R;}
A  if("mul"==ll.nm){z.v=scan(r.v.as(f64),0,AF_BINARY_MUL);R;}
A  if("min"==ll.nm){z.v=scan(r.v.as(f64),0,AF_BINARY_MIN);R;}
A  if("max"==ll.nm){z.v=scan(r.v.as(f64),0,AF_BINARY_MAX);R;}
A  mapop(mfn,ll,p);z.v=array(z.s,f64);A t(z.r?z.r-1:0,z.s,r.v(0));
A  DO(t.r,t.s[i]=t.s[i+1]);t.s[t.r]=1;I tc=(I)cnt(t);
A  DO(rc,t.v=r.v(i,span).as(f64);I c=i;
A   DO(c,mfn(t,A(t.r,t.s,r.v(c-(i+1),span)),t,p))
A   z.v(i,span)=t.v)}
A MF(scf_o){z.r=r.r;z.s=r.s;I ra=r.r?r.r-1:0;I rc=(I)r.s[ra];
A  if(1==rc){z.v=r.v;R;}if(!cnt(z)){z.v=scl(0);R;}
A  if("add"==ll.nm){z.v=scan(r.v.as(f64),ra,AF_BINARY_ADD);R;}
A  if("mul"==ll.nm){z.v=scan(r.v.as(f64),ra,AF_BINARY_MUL);R;}
A  if("min"==ll.nm){z.v=scan(r.v.as(f64),ra,AF_BINARY_MIN);R;}
A  if("max"==ll.nm){z.v=scan(r.v.as(f64),ra,AF_BINARY_MAX);R;}
A  z.v=array(z.s,f64);A t(z.r?z.r-1:0,z.s,r.v(0));t.s[ra]=1;
A  I tc=(I)cnt(t);af::index x[4];mapop(mfn,ll,p);
A  DO(rc,x[ra]=i;t.v=r.v(x[0],x[1],x[2],x[3]).as(f64);I c=i;
A   DO(c,x[ra]=c-(i+1);
A    mfn(t,A(t.r,t.s,r.v(x[0],x[1],x[2],x[3])),t,p))
A   x[ra]=i;z.v(x[0],x[1],x[2],x[3])=t.v)}
A
```

```
A EXPORT A*mkarray(lp*d){A*z=new A;cpda(*z,d);R z;}
A EXPORT V frea(A*a){delete a;}
A EXPORT V exarray(lp*d,A*a){cpad(d,*a);}
A EXPORT V afsync(){sync();}
A EXPORT Window *w_new(char *k){R new Window(k);}
A EXPORT I w_close(Window*w){R w->close();}
A EXPORT V w_del(Window*w){delete w;}
A EXPORT V w_img(lp*d,Window*w){A a;cpda(a,d);
A  w->image(a.v.as(a.r==2?f32:u8));}
A EXPORT V w_plot(lp*d,Window*w){A a;cpda(a,d);w->plot(a.v.as(f32));}
A EXPORT V w_hist(lp*d,D l,D h,Window*w){A a;cpda(a,d);
A  w->hist(a.v.as(u32),l,h);}
A EXPORT V loadimg(lp*z,char*p,I c){array a=loadImage(p,c);
A  A b(a.numdims(),a.dims(),a.as(s16));cpad(z,b);}
A EXPORT V saveimg(lp*im,char*p){A a;cpda(a,im);
A  saveImageNative(p,a.v.as(a.v.type()==s32?u16:u8));}
```

:EndNamespace