

# ⌈ The Co-dfns Compiler

## ⌈ High-performance, Parallel APL Compiler

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### :Namespace CODFNS

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⌈IO ⌈ML ⌈WX ← 0 1 3
VERSION ← 2018 1 0
AFΔPREFIX ← '/usr/local'
AFΔLIB ← ''
VSΔPS ← '\2017\o, "Enterprise' Professional' Community', " C\VC\Auxiliary\Build'
VSΔPS ,← C' 14.0\VC'
VSΔPS ,← C\Program Files (x86)\Microsoft Visual Studio'
VSΔPS ,← C\vcvarsall.bat'

Cmp ← { _ ← 1 ⌈DELETE α, soext θ
      _ ← (⌈opsys'vsc'gcc'clang') α ⌈ (α, '.cpp') put~ gc tt ⊃ a n ← ps ω
      _ ← ⌈NEXISTS α, soext θ ⌈ _ : n
      'COMPILE ERROR' ⌈SIGNAL 22}

MkNS ← {NS ⌈ α ⌈ {NS.⌈α mkf ω} (1 = 1 ⌈ ⌈ω) ≠ 0 ⌈ ⌈ω ⌈ NS ← #.⌈NS θ}
Fix ← {α MkNS α Cmp ω}
Xml ← {⌈XML (0 ⌈ ⌈ω), (⌈⌈⌈ 2 ↑ 1 ↓ ⌈ω), (C"), ⌈(C(⌈3 + ≠⌈ω) ↑, "nrsgvyel'), ⌈⌈⌈ ↓ ⌈⌈, ⌈⌈ 3 ↓ ⌈ω}
MKA ← {mka ⊂ ω ⌈ 'mka' ⌈NA 'P ', (α, soext θ), '|mkarray <PP'}
EXA ← {exa θ ω ⌈ 'exa' ⌈NA (α, soext θ), '|exarray >PP P'}
FREA ← {frea ω ⌈ 'frea' ⌈NA (α, soext θ), '|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 θ), '|', (⌈'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 ω ⌈ dya 0 α ω} ⌈ 0}
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ccf ← { ' -o ' , ω , ' . ' , α , ' ' ' ' ' , ω , ' .cpp ' ' -laf' , AFΔLIB , ' > ' , ω , ' .log 2>&1' }
cci ← { '-I' , AFΔPREFIX , '/include' ' ' -L ' , AFΔPREFIX , '/lib' ' ' }
cco ← '-std=c++11 -Ofast -g -Wall -fPIC -shared'
ucc ← { ω ω (□SH α α , ' ' , cco , cci , ccf) ω }
gcc ← 'g++' ucc 'so'
clang ← 'clang++' ucc 'dylib'
vsco ← { z ← '/W3 /wd4102 /wd4275 /Gm- /O2 /Zc:inline /Zi /Fd" , ω , ' .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' , AFΔLIB , ' .lib" '
z , '/OPT:ICF /ERRORREPORT:PROMPT /TLBID:1 ' }
vsc0 ← { ~ √ b ← □NEXISTS VSΔPS : 'MISSING VISUAL C++' □SIGNAL 99 ◇ " " , " amd64" , ~ ∇ b ≠ VSΔPS }
vsc1 ← { && cd " , ( ∇ □CMD 'echo %CD%' ) , " && cl ' , (vsco ω) , '/fast " , ω , ' .cpp " ' }
vsc2 ← { (vslo ω) , '/OUT:" , ω , ' .dll " > " , ω , ' .log " " }
vsc ← { □CMD ('%comspec% /C ' , vsc0 , vsc1 , vsc2) ω }

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fΔ ← 'ptknrsgvyeld' ◇ NΔ ← 'AEFOGLMNPVZ'
□FX0□0 fΔ , " ← { 'o , " (□1 ≠ fΔ) , " C' = ω }'
□FX0□0 NΔ , " ← { 'o , " (□1 ≠ NΔ) , " C' = tω }'
□FX0□0 'GLM' , " ← { (0 ' ' 'o , " 'GLM' , " C' ' ' 0 0) wrap catv ω }'
□FX0□0 'AEFO' , " ← { (0 ' ' 'o , " 'AEFO' , " C' ' ' α α 0) wrap catv ω }'
N ← { 0 'N' 0 (□ω) } ◇ P ← { 0 'P' 0 ω } ◇ V ← { 0 'V' α α (□ω) } ◇ Z ← { 0 'Z' 1 (□ω) }
□FX0□0 NΔ , " C's ← { ω }' ◇ at ← { α α ω ω } ◇ new ← { ω }

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wrap ← ∇ { ω (∇ + ×) ω ≠ 10 ≠ ω } @0
catv ← (≠ ∇) { C (□ω) + α ≠ + ∇ 0 , 1 ∇ α } @0 (□ ∇ ∇) (C 4 ρ C θ) , ∇

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Display ← { α ← 'Co-dfns' ◇ W ← wnew C α ◇ 777 :: wdel W
wdel W ∇ W α { wclose α : □ □SIGNAL 777' ◇ α α α ω } * ω ω ∇ ω }

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LoadImage ← { α ← 1 ◇ □ loadimg θ ω α }
SaveImage ← { α ← 'image.png' ◇ saveimg (□ω) α }
Image ← { ~ 2 3 ∇ . = ≠ ρ ω : □SIGNAL 4 ◇ (3 ≠ 2 ∇ 3 ∇ ρ ω) ∧ 3 = ≠ ρ ω : □SIGNAL 5 ◇ ω ∇ wimg (□ω) α }
Plot ← { 2 ≠ ≠ ρ ω : □SIGNAL 4 ◇ ~ 2 3 ∇ . = 1 ∇ ρ ω : □SIGNAL 5 ◇ ω ∇ wplot (□ω) α }
Histogram ← { ω ∇ whist ω , α }

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∇ r ← List
r ← □NS 1 ρ C θ ◇ r.Name ← , " C'Compile' ◇ r.Group ← C 'CODFNS'
r[0].Desc ← 'Compile an object using Co-dfns'
r.Parse ← C '2S -af=cpu opencv cuda '
∇

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Convert ← { α (□SE.SALT.Load '[SALT]/lib/NStoScript -noname').ntgennscode ω }
Run ← { C I ← ω ◇ in out ← I.Arguments ◇ AFΔLIB ◇ I.af " ∇ I.af ≡ 0
S ← (C ':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 } θ }
Help ← { Usage: <object> <target> [-af={cpu,opencv,cuda}] }

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∇ Z ← GfxΔInit S
'wnew' □NA 'P ' , (S , soext θ) , '|wnew <C [ ]'
'wclose' □NA 'I ' , (S , soext θ) , '|wclose P'
'wdel' □NA (S , soext θ) , '|wdel P'
'wimg' □NA (S , soext θ) , '|wimg <PP P'
'wplot' □NA (S , soext θ) , '|wplot <PP P'
'whist' □NA (S , soext θ) , '|whist <PP F8 F8 P'
'loadimg' □NA (S , soext θ) , '|loadimg >PP <C [ ] I'
'saveimg' □NA (S , soext θ) , '|saveimg <PP <C [ ]'
Z ← 0 0 ρ θ

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∇

[illegible]

$Sfn \leftarrow aws\_s (('TFF\Box\_tk) \_o ('TFFI\Box\_tk)) \_s aws\_as \{P \Phi \in \omega\}$   
 $Prim \leftarrow prim\_as P$   
 $Vt \leftarrow \{((0 \Box \Box \alpha) \wr \omega) 1 \Box \alpha \bar{\cdot} \bar{\cdot} 1\}$   
 $Var \leftarrow \{\alpha (aaww\_o aw\_o (name\_as \Phi) \_t (\alpha \alpha = Vt) \_as (\omega \omega V \circ, \circ \rhd)) \omega\}$   
 $Num \leftarrow float\_o int\_as (N \circ \Phi)$   
 $Strand \leftarrow 0 Var 'a' \_s (0 Var 'a' \_some) \_as ('s' A \circ \Phi)$   
 $Pex \leftarrow \{\alpha (rpar\_s Ex\_s lpar) \omega\}$   
 $Atom \leftarrow Strand\_o (0 Var 'a' \_as ('v' A)) \_o (Num\_some\_as ('n' A \circ \Phi)) \_o Pex$   
 $Brk \leftarrow rbrk\_s \{\alpha (Ex\_opt\_s (semi\_s (Ex\_opt) \_any)) \omega\} \_s lbrk\_as ('i' E \circ \Phi)$   
 $Idx \leftarrow Brk\_s (\_yes\_as \{P, ['']\} \_s Atom\_as (2 E \circ \Phi))$   
 $Blrp \leftarrow \{\alpha (\alpha \alpha \_s (\omega \omega Slrp \nabla)) \omega\}$   
 $Slrp \leftarrow \{\alpha (\alpha \alpha \_o (\omega \omega \_s \nabla) \_o ((1 \_eat) \_s \nabla)) \omega\}$   
 $Fa \leftarrow \{$   
 $\quad e \leftarrow (' \omega \omega ' \alpha \alpha', ' \alpha \omega'), \circ \bar{\cdot} \bar{\cdot} 1 \Box \bar{\cdot} 1 + 3 \ 3 \ 2 \ 2 \top (6 \ 4 \ 4 \neq 1 \ 5 \ 9) + 2 \times \wr 14$   
 $\quad a \leftarrow e (\alpha \{\omega Gex\_o Ex\_o Fex Stmts \_then Fn \bar{\cdot} \alpha \alpha \bar{\cdot} \alpha\} \bar{\cdot} 2 \ 1 \vdash \omega$   
 $\quad m \leftarrow (0 = 0 \Box \Box \alpha) \wedge \wedge \neq (\vee \lambda \circ, = \bar{\cdot} \wr 14) \vee \circ, \neq \bar{\cdot} \bar{\cdot} 1 \Box \Box \alpha$   
 $\quad \sim \vee \neq m : (\wr \neq 0 \Box \Box \alpha) \theta \alpha \omega$   
 $\quad (1 = + \neq m) \wedge 2 > m \wr 1 : 0 (\wr ('F' new 1) wrap \rhd \rhd m \neq 1 \Box \Box \alpha) \alpha \omega$   
 $\quad z \leftarrow ('F' new 'a') wrap \rhd (m \neq 'F' new \bar{\cdot} 1 + \wr 14) \bar{\cdot} (wrap \circ \rhd) m \neq 1 \Box \Box \alpha$   
 $\quad 0 (\wr, \wr z) \alpha \omega\}$   
 $Fn \leftarrow \{$   
 $\quad ns \leftarrow n z \neq \bar{\cdot} m \leftarrow \{(F_m \omega) \wedge \bar{\cdot} 1 \in \bar{\cdot} k \omega\} z \leftarrow \rhd \bar{\cdot} / \omega \diamond 0 = \neq ns : 0 (\wr, \wr z) \alpha \bar{\cdot}$   
 $\quad p \leftarrow \alpha \circ Fa \bar{\cdot} ns \diamond 0 < c \leftarrow \wr / \rhd \bar{\cdot} p : c \theta \alpha \omega$   
 $\quad 0 (\bar{\cdot} / (\wr 0 \ 4 \rho \theta), \bar{\cdot} p \{\omega ((d + \circ \rhd \bar{\cdot}), 1 \downarrow \bar{\cdot} 1 \vdash) \rhd \bar{\cdot} / 1 \rhd \alpha\} \bar{\cdot} at\{m\} \downarrow z) \alpha \bar{\cdot}\}$   
 $Pfe \leftarrow \{\alpha (rpar\_s Fex\_s lpar) \omega\}$   
 $Bfn \leftarrow rbrk Blrp lbrk\_as ('F' new \bar{\cdot} 1, \circ \wr \circ \Phi 1 \downarrow \bar{\cdot} 1 \downarrow \vdash)$   
 $Fnp \leftarrow Prim\_o (1 Var 'f') \_o Sfn\_o Bfn\_o Pfe$   
 $Mop \leftarrow \{\alpha ((mop\_as P) \_s Afx\_as (1 O)) \omega\}$   
 $Dop_1 \leftarrow \{\alpha ((dop_1\_as P) \_s Afx\_as (2 O \circ \Phi)) \omega\}$   
 $Dop_2 \leftarrow \{\alpha (Atom\_s (dop_2\_as P) \_s Afx\_as (2 O \circ \Phi)) \omega\}$   
 $Dop_3 \leftarrow (dop_3\_as P) \_s Atom\_as (2 O \circ \Phi) \_o (dot\_s jot\_as (P \circ \Phi) \_as (1 O))$   
 $Bop \leftarrow \{\alpha (rbrk\_s Ex\_s lbrk\_s (\_yes\_as \{P, ['']\} \_s Afx\_as (2 O \circ \Phi)) \omega\}$   
 $Afx \leftarrow Mop\_o (Fnp\_s (Dop_1\_o Dop_3\_opt) \_as (\rhd wrap / \circ \Phi)) \_o Dop_2\_o Bop$   
 $Trn \leftarrow \{\alpha (Afx\_s ((Afx\_o Idx\_o Atom) \_s (\nabla \_opt) \_opt)) \omega\} \_as ('t' F \circ \Phi)$   
 $Bind \leftarrow \{\alpha (gets\_s (name\_as \Phi) \_env (\alpha \alpha \{\rhd \Phi \omega\} \alpha \alpha \bar{\cdot} \alpha)) \_as (\omega \omega new 'b', \vdash)) \omega\}$   
 $Asgn \leftarrow gets\_s Brk\_s (name\_as \Phi \_t (0 = Vt) \_as ('a' V \circ, \circ \rhd)) \_as ('a' E \circ \Phi)$   
 $Fex \leftarrow Afx\_s (Trn\_opt) \_s (1 Bind 'F' \_any) \_as (\rhd wrap / \circ \Phi)$   
 $App \leftarrow Afx\_s (Idx\_o Atom\_s (dop2\_not) \_opt) \_as \{(\neq \omega) E \Phi \omega\}$   
 $Ex \leftarrow Idx\_o Atom\_s \{\alpha (0 Bind 'E' \_o Asgn\_o App\_s \nabla \_opt) \omega\} \_as (\rhd wrap / \circ \Phi)$   
 $Gex \leftarrow Ex\_s grd\_s Ex\_as (G \circ \Phi)$   
 $Nlrp \leftarrow sep\_o eot Slrp (lbrk Blrp rbrk)$   
 $Stmts \leftarrow \{\alpha (sep\_any\_s (Nlrp\_then (\alpha \alpha \_s eot \circ \Phi)) \_any\_s eot) \omega\}$   
 $Ns \leftarrow nss Blrp nse \_then (Ex\_o Fex Stmts \_then Fn) \_s eot \_as M$   
 $ps \leftarrow \{0 \neq \rhd c a e r \leftarrow (0 \ 2 \rho \theta) Ns \in \{\omega / \bar{\cdot} \wedge \setminus 'a' \neq \omega\} \bar{\cdot} \omega, \bar{\cdot} \Box UCS \ 10 : \Box SIGNAL \ c \diamond (\rhd \alpha) e\}$

$scp \leftarrow (+\backslash F_m) \vdash \circ \sqsubset \vdash$   
 $prf \leftarrow ((\neq \uparrow \neg 1 \downarrow \vdash (\neq) 0 \neq \vdash) \circ \uparrow or) \vdash$   
 $blg \leftarrow \{\alpha \leftarrow \vdash \diamond \alpha((prf(\uparrow / (1 \neq \vdash) \times \circ 1 (1 \downarrow \vdash) \wedge (= \vee 0 = \vdash) \circ \mathbb{Q} \vdash) \alpha \alpha (\neq \uparrow) r) \sqsubset \circ 2 \omega \omega (\neq) \alpha \alpha) \omega\}$   
 $enc \leftarrow \subset \neg, \circ \supset ((\neg, \neg, \vdash) / (C''), (\Phi \neg \vdash (\neq) 0 \neq \vdash))$   
 $veo \leftarrow \cup ((C' \% u'), (\neg primis), \neg) \sim \circ \{ \supset, / \{ C \star (1 \equiv \equiv \omega) \vdash \omega \} \neg \omega \} \neg 1 \downarrow \vdash (\neq) (\wedge \neg 0 \neq ((\supset 0 \rho \vdash) \neg))$   
 $ndo \leftarrow \{\alpha \leftarrow \vdash \diamond m \supset \circ (C, \vdash) \neg \alpha \alpha \alpha \neg \omega \supset \circ (\circ \neg C) \neg m \leftarrow 1 \geq \equiv \neg \omega\}$   
 $n2f \leftarrow (\supset, /) ((1 = \equiv) \supset, \circ \neg \circ C) \neg$   
  
 $rn \leftarrow \vdash, \circ \downarrow (1 + d) \uparrow \circ \neg 1 (+\backslash d \circ, = \circ 1 + (\uparrow / 0, d))$   
 $rd \leftarrow \vdash, (+ / \uparrow or \wedge (= \vee 0 = \vdash) \circ \mathbb{Q} \circ \uparrow or \vdash (\neq) F_m \wedge 1 \in \neg k)$   
 $df \leftarrow \vdash (\neq) (+\backslash 1 = d) (\sim \neg \in \neg (\neq) (1 = d) \wedge (\sim 'b' \in \neg k) \wedge O_m \vee F_m) \vdash$   
 $dua \leftarrow ((\neg G_m) \wedge F_m \vee \downarrow \circ prf \in r o F_s) (\neg (\neg \circ \vdash) (d (\neq) \neg) (0, 1 \downarrow (\neg \Phi \vdash) \wedge \neg = \neg 1 \Phi \neg) \neg (\neq \circ \vdash) 0 \in \neg n) \vdash$   
 $du \leftarrow \vdash (\neq \circ \sim) dua \vee \circ (\vee /) (prf \wedge (= \vee 0 = \vdash) \circ \mathbb{Q} prf (\neq) dua) \wedge \uparrow or \wedge \geq \circ \mathbb{Q} dua (\neq \circ \vdash) \uparrow or \times 0 = prf$   
 $lfh \leftarrow (0 \neq 1 \sqsubset \neg) \supset (C \circ \mathbb{Q} \circ \neg 0 'M' 0'', 0, \neg (C \neg)), \circ C \circ \mathbb{Q} \circ 1 'F' 1, (fn' enc \neg), (C \neg), 5 \downarrow \circ, 1 \uparrow \vdash$   
 $lfn \leftarrow (d, 'Of', 3 \downarrow \vdash) \circ 1 at (F_m \wedge 'b' \in \neg k) (d, 'Vf', ('fn' enc \circ \supset r), 4 \downarrow \vdash) \circ 1 at (F_m \wedge 1 \in \neg k)$   
 $lf \leftarrow (\supset \neg /) (1, 1 \downarrow F_m \wedge 1 \in \neg k) blg (\uparrow r) (C lfh \neg ((\vdash - (\supset - 2 \downarrow \supset)) d), 1 \downarrow \circ 1 \vdash) lfn) \sqsubset 1 \downarrow \vdash$   
 $dn \leftarrow ((0 \in \neg n) \wedge (A_m \wedge 'v' \in \neg k) \vee O_m \wedge 'f' \in \neg k) ((\sim \neg) (\neq \circ \vdash) (d - \neg 1 \Phi \neg), 1 \downarrow_{[1]} \vdash) \vdash$   
 $mrep \leftarrow (1 + \supset), 'P' 0 (' \neg), (C''), \neg 1 \downarrow 4 \downarrow \circ, 1 \uparrow \vdash$   
 $mreu \leftarrow \supset, 'E' 'u', (C''), \neg 1 \downarrow 3 \downarrow \circ, 1 \uparrow \vdash$   
 $mre \leftarrow (\supset \neg /) (\neg \supset V_m \vee A_m) \circ \supset \circ \Phi (\downarrow, (((\vdash \rho \neg (\neq \mathbb{Q}), \neg \neq \times 2 < \neq) mreu \neg mrep \neg (1 + d), 1 \downarrow \circ 1 \vdash) \neg \uparrow)) \vdash$   
 $mrs \leftarrow \vdash \subset_{[0]} \neg 1, 1 \downarrow d = 1 + \circ \supset d$   
 $mrk \leftarrow (\neg \circ (+ / \wedge) \circ \Phi L_m) (\uparrow \neg \circ (mre (mre mrs) \neg at (G_m \circ (\supset \neg /) 1 \uparrow \neg \vdash) \circ mrs) \downarrow) \vdash$   
 $mr \leftarrow (\supset \neg /) ((1 \uparrow \vdash), (mrk \neg 1 \downarrow \vdash)) \circ scp$   
 $ur \leftarrow ((2 \uparrow \vdash), 1, ('um' enc \circ \supset r), 4 \downarrow \vdash) \circ 1 at (E_m \wedge 'u' \in \neg k)$   
 $rt \leftarrow \vdash, (\vee \backslash F_m) + (+ \neq prf \wedge (= \vee 0 = \neg) \circ \mathbb{Q} \neg \circ \uparrow or M_s \neg G_s) - F_m$   
 $nm \leftarrow ((3 \uparrow \vdash), ('fe' enc \circ \supset r), 4 \downarrow \vdash) \circ 1 at ((0 \in \neg n) \wedge E_m \vee O_m \vee A_m)$   
 $lgg \leftarrow (\neg / 1 \downarrow \vdash) \neg \circ \neg \neg \neg (((\neg 1 + d), 2, \neg t, k, n, r, \circ s) \neg \neg 3, 'V', 'a', 3 (\downarrow \circ 1) 1 \uparrow \vdash) \circ \supset 1 \uparrow \vdash$   
 $lg \leftarrow (\supset \neg /) \vdash ((C \neg (\neq \circ \sim) (\vee \backslash \vdash)), (((1 \uparrow \vdash) lgg \vdash \subset_{[0]} \neg d = 1 + \supset) \neg \subset_{[0]} \neg)) G_m \wedge 1 \Phi E_m$   
 $fet \leftarrow (d, 'V' 0, 3 \downarrow \vdash) \circ 1 at (0, 1 \downarrow E_m \vee O_m \vee A_m) (d, 'Av', 3 \downarrow \vdash) \circ 1 at (E_m \wedge 'b' \in \neg k)$   
 $fee \leftarrow (\neg / \Phi) (M_m \vee E_m \vee O_m \vee A_m) blg \vdash ((\supset \circ \Phi \vdash) (C (d - \neg \circ \supset), 1 \downarrow \circ 1 \vdash) ofet \neg \neg 1 \downarrow \circ 1 \vdash) \sqsubset \supset, \neg 1 \downarrow \vdash$   
 $fe \leftarrow (\supset \neg /) (+\backslash d \leq g) (C (\vdash \uparrow \neg 1 = \circ \neq \vdash) \neg \circ \supset ofe \vdash) \sqsubset \vdash$   
 $can \leftarrow (+\backslash A_m \vee O_m) ((1 \uparrow \vdash), \circ (C (\neg 1 + 2 \downarrow \neq) \supset (C \circ C \supset), C) \circ n 1 \downarrow \vdash) \sqsubset \vdash$   
 $cas \leftarrow (\neg 1 \Phi (A_m \vee O_m) \wedge 'vf' \in \neg k) \vee (\downarrow prf) \in or \vdash (\neq) A_m \wedge 'n' \in \neg k$   
 $ca \leftarrow (can \vdash (\neq) cas \vee A_m \vee O_m \wedge 'f' \in \neg k) \neg at (A_m \vee O_m \wedge 'f' \in \neg k) \theta, \circ C \neg \vdash (\neq \circ \sim) cas$   
 $lj \leftarrow (\supset \neg /) (1 \uparrow scp), ((\vdash \neg 2 'L' 0 0, 2'', \neg 2 \downarrow 4 \downarrow \circ, 1 \uparrow \vdash) \neg 1 \downarrow scp)$   
 $sd \leftarrow (\supset \neg /) (1 \uparrow scp), (n F_s) (d, 'Vf', (C \neg), 4 \downarrow \vdash) \circ 1 at ((C, 'V') \in \neg n) \neg 1 \downarrow scp$   
 $inm \leftarrow \vee \neq \neg 1 (\Phi \vee \vdash) 1 2 (\Phi \vee \vdash) (\neg 2 \Phi E_m \wedge_{[1]} 1 2 \circ, = k) \wedge \circ 1 V_m \wedge n \in \circ n F_s$   
 $inp \leftarrow (E_m \wedge \neg) \vee 1, 2 \neq \neg$   
 $inza \leftarrow (1 \uparrow 1 \downarrow \neg) (\neq \circ \neq) at ((C, 'a') \in \neg n) (\neg 1 \uparrow \neg) (\neq \circ \neq) at ((C, 'w') \in \neg n) \vdash$   
 $inz \leftarrow (1 \uparrow \neg) (d, t, k, 3 \downarrow \circ 1 (\neq \circ \neq)) at (0, \neg 2 \neq \circ \Phi (\vee \circ \Phi E_m)) inza$   
 $inn \leftarrow (3 \uparrow \circ 1 \vdash), ((\neg \rho \neg 1 + 0 \uparrow (\uparrow / \circ n G_s)) (('fe' \equiv 2 \uparrow \vdash) \supset (C \neg), \circ C 'fe', (\Phi \neg), 2 \downarrow \vdash) \neg n), (4 \downarrow \circ 1 \vdash)$   
 $ins \leftarrow \neg (d, t, k, ((1000 \times 1 + \neg) + 1 + n + (\uparrow / n)), 4 \downarrow \circ 1 \vdash) at (L_m \vee G_m) inn$   
 $inr \leftarrow 1, \circ \neg \vdash inz \neg (1 \neq \vdash) ins \neg ((\supset \circ n \neg) \neg ((\supset n (\neq) V_m \wedge 'f' \in \neg k) \neg)) \supset \neg (C 1 \downarrow \neg) \neg, \circ C \neg \vdash$   
 $in \leftarrow (\supset \neg /) \circ (\vdash /) (1 \downarrow scp) inr \circ ((0 \rho \subset 0 8 \rho 0), \vdash /) at (\neg /) inm ((\supset \neg inp \subset E_m \wedge \neg), \circ \neg inp \subset_{[0]} \vdash) \vdash$

$pcc \leftarrow (C \vdash (\neq) A_m \vee O_m \wedge 'f' \in \sim k) \circ ((1 \cup \sim n) \sqcap \ddot{0} 2 (1 \upharpoonright \neq) \uparrow \vdash) \circ (\supset \neg \neq) \circ \Phi (\neq \vdash)$   
 $pcb \leftarrow ((\wedge, (= \vee 0 = \neg) \circ \neg) \ddot{0} 2 1 \sim \circ \uparrow \text{or } M_s \neg F_s) pcc \ddot{0} 1 ((\vdash (\neq) (d = g) \wedge A_m \vee E_m \vee O_m) \neg scp)$   
 $pcv \leftarrow (d, 'V', ('a f' \supset \neg \circ \neg O_m), (\supset \neg v), r, s, (C \theta), \sim \circ \neg g) \text{ at } (O_m \vee A_m \wedge 'v' \in \sim k)$   
 $pc \leftarrow (\supset \neg /) pcb \{ (pcv d (\neg, 1 \downarrow \ddot{0} 1 \vdash) (\alpha \uparrow \sim 1 \upharpoonright \neq \alpha) \sqcap \ddot{0} 2 \sim (n \alpha) \wr n) \text{ at } (V_m \wedge (n \alpha) \in \sim n) \omega \} \neg scp$   
 $da \leftarrow \vdash (\neq \circ \sim) (A_m \wedge d = g) \vee (0, \sim 2 \wedge / L_m) \vee (L_m \wedge \neg 1 \Phi A_m \wedge d = g) \vee O_m \wedge ('f' \in \sim k) \wedge 1 \neq d$   
 $fce \leftarrow (\supset \text{on } P_s) \{ C \Phi ' \omega', \sim (\neq \omega) \supset \neg (\alpha, ' \supset ') (' \supset ', \alpha, ' / ') \} (\vee A_s)$   
 $fcm \leftarrow (\wedge / E_m \vee A_m \vee P_m) \wedge \circ \sim 'u i' \in \sim \circ \supset \circ \supset k$   
 $fc \leftarrow ((\supset \neg /) (((d, 'An', 3 \downarrow \neg 1 \downarrow), 1 \uparrow \vdash), fce) \neg \text{ at } (fcm) \neg) ('MFOEL' \in \sim t) \subset_{[0]} \vdash$   
 $ce \leftarrow (+ \setminus F_m \vee G_m \vee E_m \vee O_m \vee L_m) ((\neg 1 \downarrow \circ, 1 \uparrow \vdash), \circ C (\supset \circ v 1 \uparrow \vdash), \circ (A_m \supset \neg \circ \downarrow n, \circ \neg \text{on } 2 f v) 1 \downarrow \vdash) \sqcup \vdash$   
 $ll \leftarrow (\vdash (\neq) 1 \Phi L_m) (((C C \% l'), \circ C \neg \text{on } \neg), \sim \neg 1 \downarrow \ddot{0} 1 \vdash) \text{ at } L_m \vdash$   
 $fv \leftarrow (\supset \neg /) (((1 \downarrow \vdash) \neg \sim (, 1 \uparrow \vdash), \circ C \text{on } \neg 1 \uparrow \vdash) \neg scp)$   
 $nv \leftarrow (\neg 1 \downarrow \ddot{0} 1 \vdash), (\neg 1 \Theta \neq \supset \vdash, \circ C \sim (C \% u' \% f' \% u'), (C \% u' \% i', \vdash), (C (C \% u'), \vdash)) \neg \circ v$   
 $lt \leftarrow (C \theta), \sim \vdash$   
 $val \leftarrow (n \wr \cup n), \neg \vdash (\vdash + (\neq \neg) \times 0 = \vdash) ((/ (1 \neq) \times \ddot{0} 1 (\cup n) \circ ((C \neg) \in \vdash) (n 2 f' v))$   
 $vag \leftarrow \wedge \circ \sim \circ (\circ, = \sim \circ 1 \neq) \sim (\circ, (((1 \sqcap \vdash) > 0 \sqcap \neg) \wedge (0 \sqcap \vdash) < 1 \sqcap \neg) \sim val)$   
 $vae \leftarrow (\cup n) (\neg, \ddot{0} 0 \neg (\sqcap \sim \ddot{0} 1 0) \circ \supset ((\vdash, \circ \supset (1 \circ \neq \neg) \sim \vdash (\neq) (\neq \vdash) \uparrow \neg) / \circ \Phi (C \theta), \circ \downarrow \vdash)) vag$   
 $vac \leftarrow (((0 \sqcap \circ \neg) \neg) \wr \circ C \vdash) \supset (1 \sqcap \circ \neg \neg), \circ C \vdash) \text{ ndo}$   
 $va \leftarrow ((\supset \neg /) (1 \uparrow \vdash), (((vae E_s) (d, t, k, (\neg vac n), r, s, g, y, \circ \neg \sim (C \neg) vac \neg v) \vdash) \neg 1 \downarrow \vdash)) scp$   
 $avb \leftarrow \{ (((, ' \alpha \omega') \uparrow \sim 1 \downarrow \rho) \neg \vdash) \alpha \sqcap \sim \ddot{0} 2 0 \vdash \alpha \alpha \wr \alpha \alpha \cap \sim (\downarrow (\Phi 1 + \circ 1 0 \wr \vdash) ((\neq \vdash) \uparrow \uparrow) \ddot{0} 0 1 \vdash) \supset r \omega \}$   
 $avi \leftarrow \neg 1 0 + (\rho \neg) \top (\neg, \neg) \wr (C \vdash)$   
 $avh \leftarrow \{ C \omega, (n \omega) ((\alpha \alpha (\omega \omega avb) \omega) \{ \alpha \alpha avi \text{ ndo } (C \alpha), \omega \}) \neg v \omega \}$   
 $av \leftarrow (\supset \neg /) (+ \setminus F_m) \{ \alpha ((\alpha ((\cup \circ \Phi (0 \rho C''), n) E_s) \sqcup \omega) avh (r (1 \uparrow \omega) \neg F_s \omega)) \sqcup \omega \} \vdash$   
 $rlf \leftarrow (\Phi \downarrow (((1 \supset \neg) \cup \vdash \sim 0 \sqcap \neg) / \circ \Phi (C \theta), \uparrow) \ddot{0} 0 1 \sim 1 + \circ 1 \neq) (\Theta 1 \Theta n, \ddot{0} 0 (C \neg) \text{ veo} \neg v)$   
 $rl \leftarrow \vdash, \circ (\supset, /) (C \text{on } O_s \neg F_s) rlf \neg scp$   
 $vc \leftarrow (\supset \neg /) (((1 \downarrow \vdash) \neg \sim (1 \uparrow \vdash), (\neq \circ \cup \text{on } E_s), 1 \neg 3 \uparrow \vdash) \neg scp)$   
 $eff \leftarrow (\supset \neg /) \vdash (((C \circ \neg \circ \neg d, 'Fe', 3 \downarrow, 1 \uparrow \neg), 1 \downarrow \vdash) (d = \circ \supset d) \subset_{[0]} \vdash$   
 $ef \leftarrow (F_m \wedge \neg 1 = \circ \times \circ \supset \neg y) ((\supset \neg /) (C \vdash (\neq) \circ \sim (\vee \neg)), (eff \neg \subset_{[0]})) \vdash$   
 $ifn \leftarrow 1 'F' 0 'Init' \theta 0 1, (4 \rho 0) \theta \theta, \sim \vdash$   
 $if \leftarrow (1 \uparrow \vdash) \neg (\vdash (\neq) O_m \wedge 1 = d) \neg ((\vdash \text{ wrap} \sim \circ ifn \circ \neq \circ \cup n) \vdash (\neq) E_m \wedge 1 = d) \neg (\vee \setminus F_m) (\neq \vdash) \vdash$   
 $fgz \leftarrow (1 \uparrow \vdash) \neg (((\neg 1 + d), 1 \downarrow \ddot{0} 1 \vdash) 1 \downarrow \vdash) \neg 2, 'G', 1, 3 \downarrow \ddot{0} 1 (\neg 1 \uparrow \neg 1 \downarrow \ddot{0} 1 \vdash), \text{on } 1 \uparrow \vdash$   
 $fg \leftarrow (\supset \neg /) (fgz \neg \text{ at } (G_m \circ (\supset \neg /) 1 \uparrow \neg \vdash) \vdash \subset_{[0]} \sim d = 2 \wr g)$   
 $fft \leftarrow (, 1 \uparrow \vdash) (1 'Z', (2 \downarrow \neg 5 \downarrow \neg), (v \neg), n, y, (C 2 \uparrow \circ, \circ \supset \circ \supset e), l) (\neg 1 \uparrow E_s)$   
 $ff \leftarrow ((\supset \neg /) (1 \uparrow \vdash), (((1 \uparrow \vdash) \neg (((\neg 1 + d), 1 \downarrow \ddot{0} 1 \vdash) 1 \downarrow \vdash) \neg fft) \neg 1 \downarrow \vdash)) scp$   
 $fd \leftarrow (1 \uparrow \vdash) \neg ((1, 'Fd', 3 \downarrow \vdash) \ddot{0} 1 F_s) \neg 1 \downarrow \vdash$

$tta \leftarrow (f \circ da \circ (pc \star \equiv) \circ mr \star \equiv) \circ in \star 3 \circ sd \circ l j \circ ca \circ f e \circ l g \circ n m \circ r t \circ m r \circ d n \circ l f \circ d u \circ d f \circ r d \circ r n$   
 $tt \leftarrow f d \circ f f \circ f g \circ i f \circ f e \circ f v \circ c \circ r l \circ a \circ v \circ a \circ l t \circ n \circ v \circ f \circ l l \circ c e \circ u \circ r \circ t \circ t \circ a$

```

E1 ← { 'fn' gcl ((C n, o ⊃ v), e, y) ω }
E2 ← { 'fn' gcl ((C n, o ⊃ v), e, y) ω }
Ei ← { r l f ← ⊃ v ω ◊ ((C n ω) ('fn' var) ⊃ ⊃ e ω), '=' , ((C n ω) ('fn' var) 1 ⊃ ⊃ e ω), ';' , nl }
O1 ← { 'op' gcl ((C n, o ⊃ v), e, y) ω }
O2 ← { 'op' gcl ((C n, o ⊃ v), e, y) ω }
O0 ← { }
Of ← { 'EF' (, ('Δ' □ R' ___' ⊃ n ω), ', ', (C n ω), ', ') ; ', nl }
Fd ← { 'FP' (, (C n ω), ', ') ; ', nl }
F0 ← { 'DF' (, (C n ω), ' _ f ) { ', nl, 'A*env[]={tenv}' ; ', nl }
F1 ← { 'DF' (, (C n ω), ' _ f ) { ', nl, ('env0' dnv ω), (fnv ω) }
G0 ← { v ← (C n ω) (" var) 1 ⊃ ⊃ e ω
      'if (1!=cnt('v, '))err(5); if('v, 'v.as(s32).scalar<I>()) { ', nl }
G1 ← { 'z=' , ((C n ω) (" var) ⊃ ⊃ e ω), '; goto L, (Φ ⊃ l ω), ';' ; ', nl }
L0 ← { 'z=' , a, ';' ; L, (Φ ⊃ n ω), ':' , (a ← (1 ⊃ ⊃ v ω) (" var) 1 ⊃ ⊃ e ω), '=z;' ; ', nl }
Z0 ← { }', nl, nl }
Z1 ← { }', nl, nl }
Ze ← { }', 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 ← { ⊃, / ((1 ≠ ⊃ n ω) ((¬ sts'' (C l), '' ⊃ s), ', '}', nl, ¬ ste'' (C n) var'' ⊃ r) ω), ', '}', nl }

gc ← { ⊃, / { 0 = ⊃ t ω : C 5 p θ ◊ C (Φ ⊃ t ω), Φ ⊃ k ω) ω } ö 1 ⊢ ω }

syms ← , " '+' '-' 'x' '÷' '*' 'θ' '|' 'o' 'L' 'f' '!'
nams ← 'add' 'sub' 'mul' 'div' 'exp' 'log' 'res' 'cir' 'min' 'max' 'fac'
syms ← , " '<' '≤' '=' '≥' '>' '≠' '~' '^' 'v' '∧' '∨'
nams ← 'lth' 'lte' 'eql' 'gte' 'gth' 'neq' 'not' 'and' 'lor' 'nan' 'nor'
syms ← , " '[]' '[' ']' 'p' ',' 's' 'φ' 'ø' 'ø' 'e' 'ε' 'ε'
nams ← 'sqd' 'brk' 'iot' 'rho' 'cat' 'ctf' 'rot' 'trn' 'rtf' 'mem' 'dis'
syms ← , " '≡' '≠' 'h' 'h' 'T' 'L' '/' 'f' '\' 'x' '?'
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 ← , " 'Δ' 'Φ' 'o' 'ε' 'c' '⊕' '⊖FFT' '⊖IFFT' '%u'
nams ← 'gdu' 'gdd' 'oup' 'fnd' 'par' 'mdv' 'fft' 'ift' "

nl ← □ UCS 13 10 ◊ fvs ← , ö 0 ( / ~ ) 0 ≠ ( ≠ o p'' ¬ ) ◊ cln ← '-' □ R '-' ◊ cnm ← (syms 1 C) ⊃ (nams, C)
lits ← { 'A(0, eshp, constant(' , (cln Φ ω), ', eshp, ', ('f64' 's32' ⊃ ~ ω = |ω), ', ')) }
litv ← { 'std::vector<', ('DI' ⊃ ~ ∧ / ω = |ω), '> {', (cln ⊃ {α, ', ', ω} / Φ'' ω), '}'.data() }
lita ← { 'A(1, dim4(' , (Φ ≠ ω), ', ), array(' , (Φ ≠ ω), ', ', (litv ω), ', ')) }
lit ← { ' ' = ⊃ 0 p ω : (cnm ω), α ◊ 1 = ≠ ω : lits ω ◊ lita ω }
var ← { α ≡, 'α' : , 'l' ◊ α ≡, 'ω' : , 'r' ◊ 1 ≥ ⊃ ω : α α lit, α ◊ 'env[' , (Φ ⊃ ω), ']' [', (Φ ⊃ Φ ω), ']' }
dnv ← { (0 ≡ z) ⊃ ('A' , α, '[' , (Φ z ← ⊃ v ω), ', ' ; ') ('A*' , α, '=NULL ; ') }
fnv ← { z ← 'A*env[' , (Φ 1 + ⊃ s ω), ']' = {', (C, / (C'env0'), {', p[' , (Φ ω), ']' }'' 1 ⊃ s ω), '}' ; ', nl }
gcl ← { z r l n ← ((3 p C'fn'), C α) { ⊃ α var / ω }'' ↓ (C ω), 1 ⊃ ω ◊ n, '(' , (C {α, ', ', ω} / z l r ~ C'fn'), ', env) ; ', nl }

```

$rth \leftarrow \{\triangleright, / (Cnl), \sim 2 \downarrow \sim 2 \downarrow c \downarrow \sim 1 + (C'rth') \downarrow \sim 3 \uparrow \cdot c \leftarrow \square SRC \square THIS\}$

```

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

```



```

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

```

```

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

```

```

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

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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);}

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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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R DF(tke_f){I lv[4];seq it[4];seq ix[4];B c=cnt(l);
R if(l.r>1||(c>r.r&&r.r))err(4);if(!c){z=r;R;}
R U rk=r.r?r.r:(U)l.s[0];z.r=rk;z.s=r.s;l.v.as(s32).host(lv);
R DO((I)c,{U j=rk-(i+1);I a=std::abs(lv[i]);z.s[j]=a;
R if(a>r.s[j])ix[j]=seq((D)r.s[j]);
R else if(lv[i]<0)ix[j]=seq((D)r.s[j]-a,(D)r.s[j]-1);
R else ix[j]=seq(a);
R it[j]=ix[j]+(lv[i]<0)*(a-(D)r.s[j]);})
R if(!cnt(z)){z.v=scl(0);R;}z.v=array(z.s,r.v.type());z.v=0;
R z.v(it[0],it[1],it[2],it[3])=r.v(ix[0],ix[1],ix[2],ix[3]);}
R MF(trn_f){z.r=r.r;DO(r.r,z.s[i]=r.s[r.r-(i+1)])
R switch(r.r){CS(0,z.v=r.v)CS(1,z.v=r.v)CS(2,z.v=r.v.T())
R CS(3,z.v=reorder(r.v,2,1,0))CS(4,z.v=reorder(r.v,3,2,1,0))}}
R DF(trn_f){I lv[4];if(l.r>1||cnt(l)!=r.r)err(5);
R l.v.as(s32).host(lv);DO(r.r,if(lv[i]<0||lv[i]>=r.r)err(4))
R U8 f[]={0,0,0,0};DO(r.r,f[lv[i]]=1)
R U8 t=1;DO(r.r,if(t&&!f[i])t=0;else if(!t&&f[i])err(5))
R DO(r.r,if(!f[i])err(16))
R z.r=r.r;DO(r.r,z.s[r.r-(lv[i]+1)]=r.s[r.r-(i+1)])
R I s[4];DO(r.r,s[r.r-(lv[i]+1)]=r.r-(i+1))
R switch(r.r){CS(0,z.v=r.v)CS(1,z.v=r.v)
R CS(2,z.v=reorder(r.v,s[0],s[1]))
R CS(3,z.v=reorder(r.v,s[0],s[1],s[2]))
R CS(4,z.v=reorder(r.v,s[0],s[1],s[2],s[3]))}}
R MF(unq_f){if(r.r>1)err(4);z.r=1;if(!cnt(r)){z.s=r.s;z.v=r.v;R;}
R array a,b;sort(a,b,r.v);z.v=a!=shift(a,1);z.v(0)=1;
R z.v=where(z.v);sort(b,z.v,b(z.v),a(z.v));
R z.s=dim4(z.v.elements());}
R DF(unq_f){if(r.r>1||l.r>1)err(4);z.r=1;dtype mt=mxt(l.v,r.v);
R if(!cnt(l)){z.s=r.s;z.v=r.v;R;}if(!cnt(r)){z.s=l.s;z.v=l.v;R;}
R array x=setUnique(l.v);B c=x.elements();
R z.v=!anyTrue(tile(r.v,1,(U)c)==tile(array(x,1,c),(U)r.s[0],1),1);
R z.v=join(0,l.v.as(mt),r.v(where(z.v)).as(mt));
R z.s=dim4(z.v.elements());}
R

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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;}

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

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A MF(rnk_o){if(cnt(wv)!=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

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```

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

```

**:EndNamespace**