ECHAM Performance Optimisation by Single Precision

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Motivation: Running a 125,000 years climate simulation on a supercomputer; at the moment would require ~ 10 years. Model needs to be optimised.
Reduced Precision in Climate Models

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Single Precision in Weather Forecasting Models: An Evaluation with the IFS (Váňa et al. - 2016)

Modification of a climate model led to a time gain of about 40%.
Reduced Precision in Climate Models

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Single Precision in Weather Forecasting Models: An Evaluation with the IFS (Váňa et al. - 2016)
Modification of a climate model led to a time gain of about 40%.

Will single precision make another climate model faster?
Will the model produce reliable climate data?
Properties of Single and Double Precision

\[ n_{dp} = (-1)^{\text{sign}} \cdot 2^{\text{Exp} - 1023} \cdot \text{Mantissa}. \quad (1 \leq \text{Exp} \leq 2046) \]

\[ n_{sp} = (-1)^{\text{sign}} \cdot 2^{\text{Exp} - 127} \cdot \text{Mantissa}. \quad (1 \leq \text{Exp} \leq 254) \]

- Double-precision can represent bigger and smaller numbers in absolute value.
- Double-precision can represent small numbers more precisely.
- Single precision saves time for operations and variable storage/retrieval.
- Single precision can save up to \( \sim 60\% \) of energy.
Properties of Single and Double Precision

\[ n_{dp} = (-1)^{\text{sign}} \cdot 2^{\text{Exp}-1023} \cdot \text{Mantissa}. \quad (1 \leq \text{Exp} \leq 2046) \]

\[ n_{sp} = (-1)^{\text{sign}} \cdot 2^{\text{Exp}-127} \cdot \text{Mantissa}. \quad (1 \leq \text{Exp} \leq 254) \]

Models don’t really need double precision, except for some parts. Truncating digits is equivalent to truncating uncertainty.

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Properties of Single and Double Precision

\[ n_{dp} = (-1)^{sign} \cdot 2^{Exp-1023} \cdot Mantissa. \quad (1 \leq Exp \leq 2046) \]

\[ n_{sp} = (-1)^{sign} \cdot 2^{Exp-127} \cdot Mantissa. \quad (1 \leq Exp \leq 254) \]

\[ n_{hp} = (-1)^{sign} \cdot 2^{Exp-15} \cdot Mantissa. \quad (1 \leq Exp \leq 30) \]
program example1
    integer :: i
    real(4) :: s
    s=0.
    do i=1,10000000
       s=s+1./i
    enddo
    print* ,s
end program

Average running time (sp): 0.091s. Result: 15.4036826827
program example1
  integer :: i
  real(8) :: s
  s=0.
  do i=1,10000000
    s=s+1./i
  enddo
  print*,s
end program
program example2
    real(4) :: a,b,c; integer :: j
    do j=1,3000000
        a=-52.; b=51.2345
        c=(a+b)/2.
        do while (abs((exp(c)-2.+sin(1./j))).ge.(0.0000001))
            if (((exp(a)-2.+sin(1./j))*(exp(c)-2.+sin(1./j))).lt.0.) then
                b=c; c=(a+b)/2.
            else
                a=c; c=(a+b)/2.
            endif
        enddo
    enddo
    print*,c,(exp(c)-2.+sin(1./j))
end program

Average time (sp): 11.775s. Result (last iteration): 0.693147063
program example2
    real(8) :: a,b,c; integer :: j
    do j=1,3000000
        a=-52.; b=51.2345
        c=(a+b)/2.
        do while (abs((exp(c)-2.+sin(1./j))).ge.(0.0000001))
            if (((exp(a)-2.+sin(1./j))*(exp(c)-2.+sin(1./j))).lt.0.) then
                b=c; c=(a+b)/2.
            else
                a=c; c=(a+b)/2.
            endif
        enddo
    enddo
    print* ,c ,(exp(c)-2.+sin(1./j))
end program

Average time (sp): 11.775s. Result (last iteration): 0.693147063
Average time (dp): 13.067s. Result (last iteration): 0.69314701877032547
The model we want to optimise is called ECHAM, it is the atmospheric component of the climate model MPI-ESM.

ECHAM Contains time-consuming code.
INTEGER, PARAMETER :: sp = SELECTED_REAL_KIND(6,37)
INTEGER, PARAMETER :: dp = SELECTED_REAL_KIND(12,307)

! Floating point working precision

INTEGER, PARAMETER :: wp = dp
**Precision Switch in ECHAM**

```fortran
INTEGER, PARAMETER :: sp = SELECTED_REAL_KIND(6,37)
INTEGER, PARAMETER :: dp = SELECTED_REAL_KIND(12,307)

! Floating point working precision

INTEGER, PARAMETER :: wp = sp
```

- Feature not fully implemented in the code.
- Precision-specific code structure:
  - Input/Output.
  - Functions (DCOS)
  - Numbers too big/small (zlimit = 1.0E-200_dp)
  - Routines causing crashes in single precision etc.
- Lack of code modularity makes everything harder.
Another strategy: Changing precision inside the code blocks (Routines)

```
↓ Input dp variables
Internal variables
Calculations
↓ Output dp variables

⇒

Input dp variables
Conversion of dp variables to sp
Internal variables in single precision
Calculations in single precision
Conversion of sp variables to dp
↓ Output dp variables
```
ELEMENTAL FUNCTION planckFunction(temp, band)
! Compute the blackbody emission in a given band as a function of temperature
!
REAL(WP), INTENT(IN) :: temp
INTEGER, INTENT(IN) :: band
REAL(WP) :: planckFunction
INTEGER :: index
REAL(WP) :: fraction
index = MIN(MAX(1, INT(temp - 159._WP)),180)
fraction = temp - 159._WP - float(index)
planckFunction = totplanck(index, band) + fraction * (totplanck(index+1, band) - totplanck(index, band))
planckFunction = planckFunction * delwave(band)
END FUNCTION planckFunction

Average time for 1 month ECHAM run: 160.47s.
ELEMENTAL FUNCTION planckFunction(temp, band)
! Compute the blackbody emission in a given band as a function of temperature
!
REAL(WP), INTENT(IN) :: temp
INTEGER, INTENT(IN) :: band
REAL(WP) :: planckFunction
REAL(SP) :: pF, tsp
INTEGER :: index
REAL(SP) :: fraction

index = MIN(MAX(1, INT(temp - 159._SP)),180)
fraction = temp - 159._SP - float(index)
tsp = REAL(totplanck(index, band),KIND=SP)
pF = tsp + fraction * (REAL(totplanck(index+1, band),KIND=SP) - tsp)
pF = pF * REAL(delwave(band),KIND=SP)
planckFunction = REAL(pF,KIND=WP)
END FUNCTION planckFunction

Average time for 1 month ECHAM run: 160.47s.
Average time for 1 month ECHAM run: 168.35s.
Routines are up to \(~ 25\%\) faster but...
Precision Change Effects

Routines are up to $\sim 25\%$ faster but conversions and additional declarations take long time

Solution: Working on bigger code blocks. Expected time gain $\geq 25\%$ for each routine.
The radiation component of the ECHAM has been separated to run in parallel in a new version (work of Mohammad Reza Heidari, DKRZ), working on it presents the several advantages:

- Radiation is modular.
- It has an own precision switch.
- Radiation and remaining atmosphere communicate through few modules.
- Contains time-consuming code.
Our final plan:

Input dp variables

Radiation

Output dp variables

Conversion of dp variables to sp
Radiation
Conversion of sp variables to dp

Output dp variables

This is work in progress

This is work in progress
ECHAM 6.03.02/p1 (1976-1981 run), brute temperature difference year 1981 (Jan, Jun, Dec):

Chaotic equations $\rightarrow$ Butterfly effect. This helps only for very short runs.
Testing Procedure

There is no standard procedure to test a climate model (!)

Evaluating year means can be one of the ways.

- Make run two models for 15 years.
- Discard the first 5 years and evaluate the year means of the remaining 10.
- Compare the subtraction of some key variables (temperature).
Surface temperature year average difference of ECHAM with mo_lrtm_gas_optics in sp/dp after 6, 10, 15 yrs
ECHAM 6.03.02/6.03.02p1 year average temperature difference after 6, 10, 15 yrs:

Difference of temp means is smaller/comparable in models with single precision parts
ECHAM Combined Modifications

tsurf year average difference of ECHAM with mo_lrtm_gas_optics and clsst in sp/dp after 6,10,15 yrs:
Errors in Precision Conversion

ECHAM-6.3.04p1, 1977-1981 spin-up, 1982-1991 tsurf year average difference with some planckFunction variables in sp (years '82, '87 and '91 plots):
Conclusions

What has to be done
- Further code modifications
- Further debugging
- Code adjustments when final results are not consistent

Conclusions
- Single precision can actually save time
- Single precision models are likely to produce reliable climate data
ECHAM testing and validation - planckFunction

ECHAM-6.3.04p1, 1977-1981 spin-up, 1982-1991 tsurf year average difference with planckFunction in sp (years '82, '87 and '91 plots), comparison with standard ECHAM model:
Errors in Precision Conversions

ECHAM-6.3.04p1, 1977-1981 spin-up, 1982-1991 tsurf year average differences with planckFunction (bad version) and mo_Lrtm_gas_optics in sp:
ECHAM-6.3.04p1, 1977-1981 spin-up, 1982-1991 tsurf year average differences with clsst in sp:
ECHAM Testing - mo_lrtm_gas_optics

ECHAM-6.3.04p1, 1977-1981 spin-up, 1982-1991 tsurf year average difference. Only taumol01 and taumol02 of mo_lrtm_gas_optics changed to sp (years ’82, ’87 and ’91 plots):