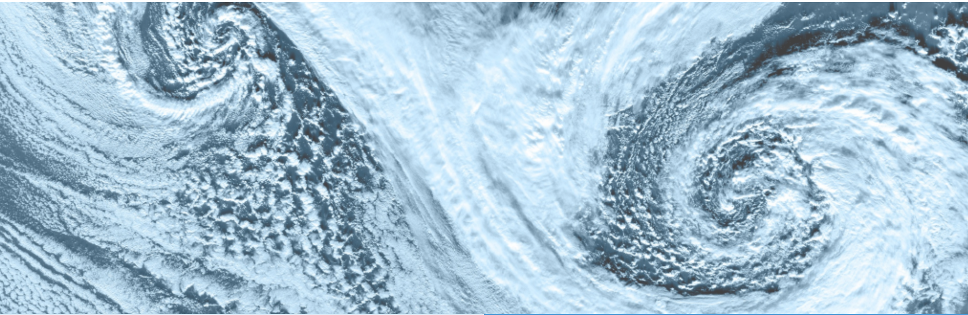
C2SM
Center for Climate
Systems Modeling

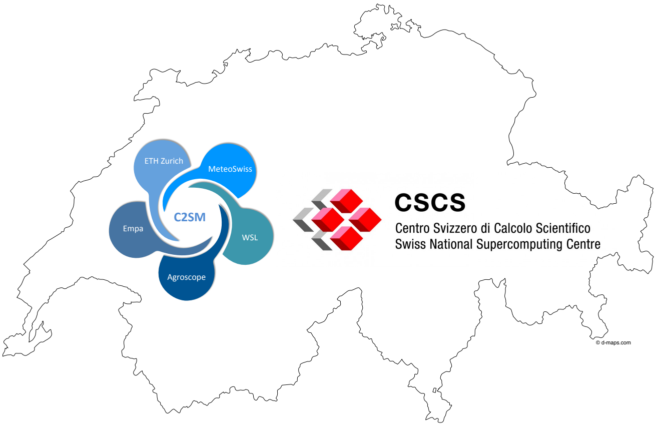
CLAW Provides High-Level Abstractions for Weather and Climate Models

ENES Workshop April 7, 2016

Jon Rood



Who is Involved in CLAW?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MeteoSwiss
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Empa
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Swiss National Supercomputing Centre
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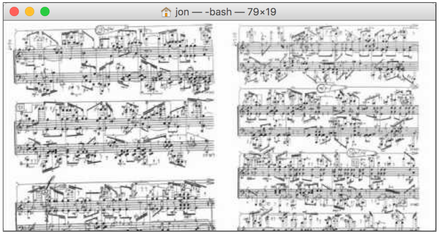
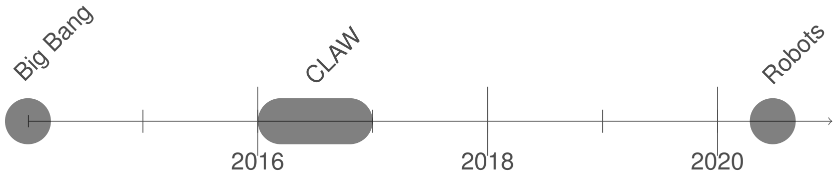
- People involved
  - Valentin Clément (C2SM), Sylvaine Ferrachat (ETH Zurich), Oliver Fuhrer (MeteoSwiss), Xavier Lapillonne (MeteoSwiss), Jon Rood (C2SM), Will Sawyer (CSCS)

What is CLAW?



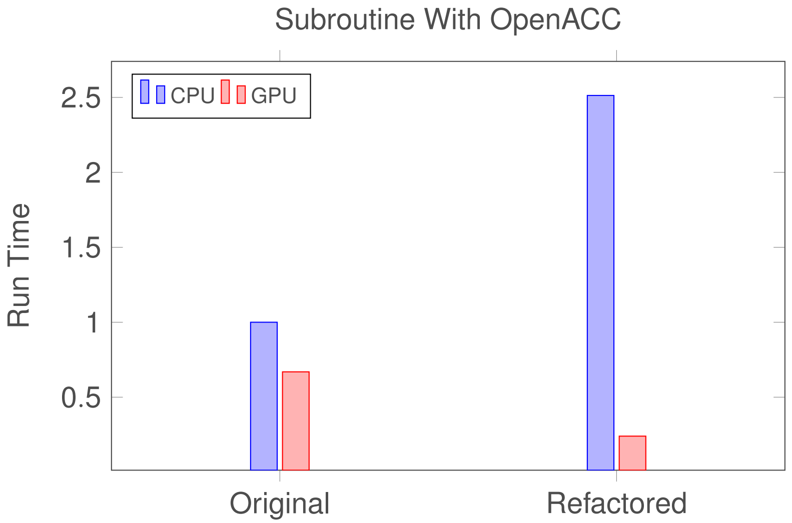
- Scientists must conduct a computational symphony of interdependent physical, virtual, and theoretical instruments of optimization
  - Machine configurations, software environments, programming languages, compilers, compiler flags, model configurations, domain-based optimizations, algorithmic optimizations, source code optimizations, etc.
- CLAW is an effort to increase the performance portability and maintainability of climate and weather codes (that are written in Fortran)

When is CLAW Happening?



- CLAW is happening right now through 2016 as a small project to develop a proof-of-concept
- Hopefully future funding possibilities will expand its functionality and abstraction

Why Develop CLAW?



Code Example Using #IFDEF

Original Subroutine

```
!$acc parallel loop gang
DO k=1,ntrac
  IF (trlist%ti(k)%nsedi==0) CYCLE
  imod=trlist%ti(k)%mode
  slinnfac=sigma(imod)**(2._dp*sigmaln(imod))
  IF (trlist%ti(k)%nphase==AEROSOLNUMBER) THEN
    !$acc parallel loop gang vector collapse(2)
    DO j=1,klev
      DO i=1,kproma
        zmd(i,j)=MIN(rwet(imod)%ptr(i,j,krow)*2._dp,50.E-6_dp)
      END DO
    END DO
  END IF
  !$acc parallel loop gang vector collapse(2)
  DO j=1,klev
    DO i=1,kproma
      zsediflux(i,j)=0._dp
      IF (zmd(i,j)>0._dp) THEN
        zxtp1=pxtm1(i,j,k)+pxtte(i,j,k)*time_step_len
        zvsedi=(2._dp/9._dp*&
          (densaer(imod)%ptr(i,j,krow)-zrho(i,j)) &
          *grav/zvis(i,j)*(zmd(i,j)/2._dp)**2._dp) &
          *(slinnfac+1.246_dp*2._dp*zlair(i,j) &
          /zmd(i,j)*exp((0.5_dp*sigmaln(imod)**2._dp)))
        zsedtend=zxtp1*zvsedi/zdz(i,j)
        pxtte(i,j,k)=pxtte(i,j,k)-zsedtend
        zsediflux(i,j)=zsedtend*zdpg(i,j)
      END IF
    END DO
  END DO
  !$acc parallel loop gang vector collapse(2)
  DO j=2,klev
    DO i=1,kproma
      pxtte(i,j,k)=pxtte(i,j,k)+(zsediflux(i,j-1)/zdpg(i,j))
    END DO
  END DO
END DO
!$acc end parallel loop
```

Refactored Subroutine

```
!$acc parallel loop gang vector collapse(2)
DO k=1,ntrac
  DO i=1,kproma
    DO j=1,klev
      IF (trlist%ti(k)%nsedi==0) CYCLE
      imod=trlist%ti(k)%mode
      slinnfac=sigma(imod)**(2._dp*sigmaln(imod))
      IF (trlist%ti(k)%nphase==AEROSOLNUMBER) THEN
        zmd=MIN(rwet(imod)%ptr(i,j,krow)*2._dp,50.E-6_dp)
      END IF
      zsediflux(j)=0._dp
      IF (zmd>0._dp) THEN
        zxtp1=pxtm1(i,j,k)+pxtte(i,j,k)*time_step_len
        zvsedi=(2._dp/9._dp*&
          (densaer(imod)%ptr(i,j,krow)-zrho(i,j)) &
          *grav/zvis(i,j)*(zmd/2._dp)**2._dp) &
          *(slinnfac+1.246_dp*2._dp*zlair(i,j) &
          /zmd*exp((0.5_dp*sigmaln(imod)**2._dp)))
        zsedtend=zxtp1*zvsedi/zdz(i,j)
        pxtte(i,j,k)=pxtte(i,j,k)-zsedtend
        zsediflux(j)=zsedtend*zdpg(i,j)
      END IF
      IF (j>1) THEN
        pxtte(i,j,k)=pxtte(i,j,k)+(zsediflux(j-1)/zdpg(i,j))
      END IF
    END DO
  END DO
END DO
!$acc end parallel loop
```

Plot generated from this example

Code Example With CLAW

Original Subroutine w/ CLAW

```
!$claw acc parallel loop gang vector collapse(2)
DO k=1,ntrac
  !$claw begin loop-hoist(j,i) loop-interchange &
  !$claw reshape(zmd(0),zsediflux(1,j))
  IF (trlist%ti(k)%nsedi==0) CYCLE
  imod=trlist%ti(k)%mode
  slinnfac=sigma(imod)**(2._dp*sigmaln(imod))
  IF (trlist%ti(k)%nphase==AEROSOLNUMBER) THEN
    DO j=1,klev
      DO i=1,kproma
        zmd(i,j)=MIN(rwet(imod)%ptr(i,j,krow)*2._dp,50.E-6_dp)
      END DO
    END DO
  END IF
  DO j=1,klev
    DO i=1,kproma
      zsediflux(i,j)=0._dp
      IF (zmd(i,j)>0._dp) THEN
        zxtp1=pxtm1(i,j,k)+pxtte(i,j,k)*time_step_len
        zvsedi=(2._dp/9._dp*&
          (densaer(imod)%ptr(i,j,krow)-zrho(i,j)) &
          *grav/zvis(i,j)*(zmd(i,j)/2._dp)**2._dp) &
          *(slinnfac+1.246_dp*2._dp*zlair(i,j) &
          /zmd(i,j)*exp((0.5_dp*sigmaln(imod)**2._dp)))
        zsedtend=zxtp1*zvsedi/zdz(i,j))
        pxtte(i,j,k)=pxtte(i,j,k)-zsedtend
        zsediflux(i,j)=zsedtend*zdpg(i,j)
      END IF
    END DO
  END DO
  DO j=2,klev
    DO i=1,kproma
      pxtte(i,j,k)=pxtte(i,j,k)+(zsediflux(i,j-1)/zdpg(i,j))
    END DO
  END DO
  !$claw end
END DO
!$claw acc end parallel loop
```

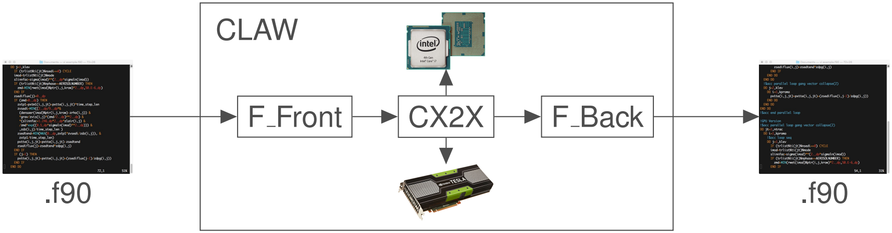
Generated Subroutine

```
!$acc parallel loop gang vector collapse(2)
DO k=1,ntrac
  DO i=1,kproma
    DO j=1,klev
      IF (trlist%ti(k)%nsedi==0) CYCLE
      imod=trlist%ti(k)%mode
      slinnfac=sigma(imod)**(2._dp*sigmaln(imod))
      IF (trlist%ti(k)%nphase==AEROSOLNUMBER) THEN
        zmd=MIN(rwet(imod)%ptr(i,j,krow)*2._dp,50.E-6_dp)
      END IF
      zsediflux(j)=0._dp
      IF (zmd>0._dp) THEN
        zxtp1=pxtm1(i,j,k)+pxtte(i,j,k)*time_step_len
        zvsedi=(2._dp/9._dp*&
          (densaer(imod)%ptr(i,j,krow)-zrho(i,j)) &
          *grav/zvis(i,j)*(zmd/2._dp)**2._dp) &
          *(slinnfac+1.246_dp*2._dp*zlair(i,j) &
          /zmd*exp((0.5_dp*sigmaln(imod)**2._dp)))
        zsedtend=zxtp1*zvsedi/zdz(i,j))
        pxtte(i,j,k)=pxtte(i,j,k)-zsedtend
        zsediflux(j)=zsedtend*zdpg(i,j)
      END IF
      IF (j>1) THEN
        pxtte(i,j,k)=pxtte(i,j,k)+(zsediflux(j-1)/zdpg(i,j))
      END IF
    END DO
  END DO
END DO
!$acc end parallel loop
```

1. Loops hoisted
2. Loop interchange
3. Arrays reshaped

How is CLAW Implemented?

- CLAW is developed by utilizing the OMNI source-to-source compiler from the Riken Institute
- Currently code exists in original CPU optimal state with CLAW directives for GPU-centric transformations
- OMNI compiler front-end generates an intermediate code representation with abstract syntax tree where transformations are performed in JAVA and the back-end generates transformed Fortran code

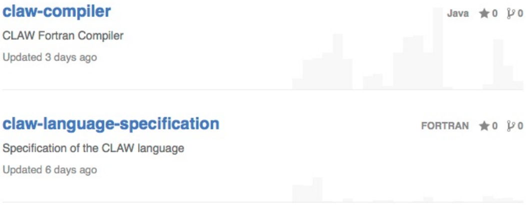


```
DO j=1,klev
  IF (trlist%ti(jt)%nsedi==0) CYCLE
  imod=trlist%ti(jt)%mode
  slinnfac=sigma(imod)**(2._dp*sigmaln(imod))
  IF (trlist%ti(jt)%nphase==AEROSOLNUMBER) THEN
    zmd=MIN(rwet(imod)%ptr(i,j,krow)*2._dp,50.E-6_dp)
  END IF
  zsediflux(j)=0._dp
  IF (zmd>0._dp) THEN
    zxtp1=pxtm1(i,j,jt)+pxtte(i,j,jt)*time_step_len
    zvsedi=MIN((2._dp/9._dp*&
     (densaer(imod)%ptr(i,j,krow)-zrho(i,j)) &
     *grav/zvis(i,j)*(zmd/2._dp)**2._dp) &
     *(slinnfac+1.246_dp*2._dp*zlair(i,j) &
     /zmd*exp((0.5_dp*sigmaln(imod)**2._dp))) &
     ,zdz(i,j)/time_step_len )
    zsedtend=MIN(MAX(0._dp,zxtp1*zvsedi/zdz(i,j)), &
     zxtp1/time_step_len)
    pxtte(i,j,jt)=pxtte(i,j,jt)-zsedtend
    zsediflux(j)=zsedtend*zdpg(i,j)
  END IF
  IF (j>1) THEN
    pxtte(i,j,jt)=pxtte(i,j,jt)+(zsediflux(j-1)/zdpg(i,j))
  END IF
END DO
                                                72,1          51%
```

```
        zsediflux(i,j)=zsedtend*zdpg(i,j)
      END IF
    END DO
  END DO
  !$acc parallel loop gang vector collapse(2)
  DO j=2,klev
    DO i=1,kproma
      pxtte(i,j,jt)=pxtte(i,j,jt)+(zsediflux(i,j-1)/zdpg(i,j))
    END DO
  END DO
END DO
!$acc end parallel loop

!GPU Version
!$acc parallel loop gang vector collapse(2)
DO jt=1,ntrac
  DO i=1,kproma
    !$acc loop seq
    DO j=1,klev
      IF (trlist%ti(jt)%nsedi==0) CYCLE
      imod=trlist%ti(jt)%mode
      slinnfac=sigma(imod)**(2._dp*sigmaln(imod))
      IF (trlist%ti(jt)%nphase==AEROSOLNUMBER) THEN
        zmd=MIN(rwet(imod)%ptr(i,j,krow)*2._dp,50.E-6_dp)
      END IF
                                                54,1          31%
```

Where is CLAW Available?



claw-compiler
CLAW Fortran Compiler
Updated 3 days ago
Java ★0 0

claw-language-specification
Specification of the CLAW language
Updated 6 days ago
FORTRAN ★0 0

https://github.com/C2SM-RCM

CLAW Progression

- CLAW development is iterating from the ‘bottom-up’
- Have begun developing most useful transformations for GPUs already seen in COSMO
- Investigating and verifying use of these transformations and searching for more in ECHAM/HAMMOZ and ICON, as well as COSMO
- Currently can perform loop reordering, loop fusion, array demotion to scalar, code removal, and vector notation to loops
- Working on loop hoisting/lowering and reshaping arrays

CLAW Progression

- After building up sufficient transformation capabilities, higher level abstractions should become possible and are desired
- Will want to expand beyond only CPU $\leftrightarrow$ GPU transformations into more architectures
- Interested in possible connection to other high level abstraction projects (DSLs, DSAs)
- Could CLAW ultimately become a transformation knowledgebase?

Questions?