LaplaceMetalSolver

Generated by Doxygen 1.12.0

Chapter 1

Class Index

1.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

Chapter 2

File Index

2.1 File List

Here is a list of all files with brief descriptions:

Chapter 3

Class Documentation

3.1 LaplaceMetalSolver::Desc Struct Reference

```
#include <LaplaceMetalSolver.hpp>
```

Public Attributes

- uint32_t nx = 0
- uint32_t ny = 0
- float dx = 1.f
- float dy = 1.f

3.1.1 Member Data Documentation

3.1.1.1 dx

```
float LaplaceMetalSolver::Desc::dx = 1.f
```

3.1.1.2 dy

```
float LaplaceMetalSolver::Desc::dy = 1.f
```

3.1.1.3 nx

```
uint32_t LaplaceMetalSolver::Desc::nx = 0
```

3.1.1.4 ny

```
uint32_t LaplaceMetalSolver::Desc::ny = 0
```

The documentation for this struct was generated from the following file:

- metal/LaplaceMetalSolver.hpp

3.2 LaplaceMetalSolver Class Reference

```
#include <LaplaceMetalSolver.hpp>
```

Classes

- struct Desc
- struct MGLevel

Public Types

- enum class Smoother { Jacobi , RBGS }

Public Member Functions

- LaplaceMetalSolver (const Desc &d, const char ∗metal_path=nullptr)
- ∼LaplaceMetalSolver ()
- void setInitial (const std::vector< float > &u0)
- void setDirichletBC (const std::vector< uint8_t > &mask, const std::vector< float > &values)
- bool solveJacobi (uint32_t max_iters, float tol, uint32_t ∗out_iters=nullptr, float ∗residual_l2=nullptr)
- bool solveRBGS (uint32_t max_iters, float tol, uint32_t ∗out_iters=nullptr, float ∗residual_l2=nullptr)
- std::vector< float > downloadSolution () const
- void setRHS (const std::vector< float > &rhs)
- bool solveRBGSWithRHS (uint32_t max_iters, float tol, uint32_t ∗out_iters=nullptr, float ∗residual_l2=nullptr)
- void setClampEnabled (bool e)
- bool clampEnabled () const
- LaplaceMetalSolver (const LaplaceMetalSolver &)=delete
- LaplaceMetalSolver & operator= (const LaplaceMetalSolver &)=delete
- void setVerbose (bool v)
- bool verbose () const
- void setDamping (float w)
- float damping () const
- void setSmoother (Smoother s)
- Smoother smoother () const
- void setRelativeTolerance (float r)
- float relativeTolerance () const
- bool solveMultigrid (uint32_t max_vcycles, float tol, uint32_t nu1=3, uint32_t nu2=3, uint32_t coarse_iters=30)
- void debugRestrictTest ()
- void debugProlongTest ()
- void debugResidualTest ()
- void debugJacobiRhsTest ()
- void debugCheckUniforms ()

Public Attributes

- std::vector< MGLevel > levels_

3.2.1 Member Enumeration Documentation

3.2.1.1 Smoother

```
enum class LaplaceMetalSolver::Smoother  [strong]
```

Enumerator

Jacobi	
RBGS	

3.2.2 Constructor & Destructor Documentation

3.2.2.1 LaplaceMetalSolver() [1/2]

```
LaplaceMetalSolver::LaplaceMetalSolver (
             const Desc & d,
             const char * metal_path = nullptr)
```

3.2.2.2 ∼LaplaceMetalSolver()

```
LaplaceMetalSolver::∼LaplaceMetalSolver ()
```

3.2.2.3 LaplaceMetalSolver() [2/2]

```
LaplaceMetalSolver::LaplaceMetalSolver (
             const LaplaceMetalSolver & )  [delete]
```

3.2.3 Member Function Documentation

3.2.3.1 clampEnabled()

```
bool LaplaceMetalSolver::clampEnabled () const  [inline]
```

3.2.3.2 damping()

```
float LaplaceMetalSolver::damping () const  [inline]
```

3.2.3.3 debugCheckUniforms()

```
void LaplaceMetalSolver::debugCheckUniforms ()
```

3.2.3.4 debugJacobiRhsTest()

```
void LaplaceMetalSolver::debugJacobiRhsTest ()
```

3.2.3.5 debugProlongTest()

```
void LaplaceMetalSolver::debugProlongTest ()
```

3.2.3.6 debugResidualTest()

```
void LaplaceMetalSolver::debugResidualTest ()
```

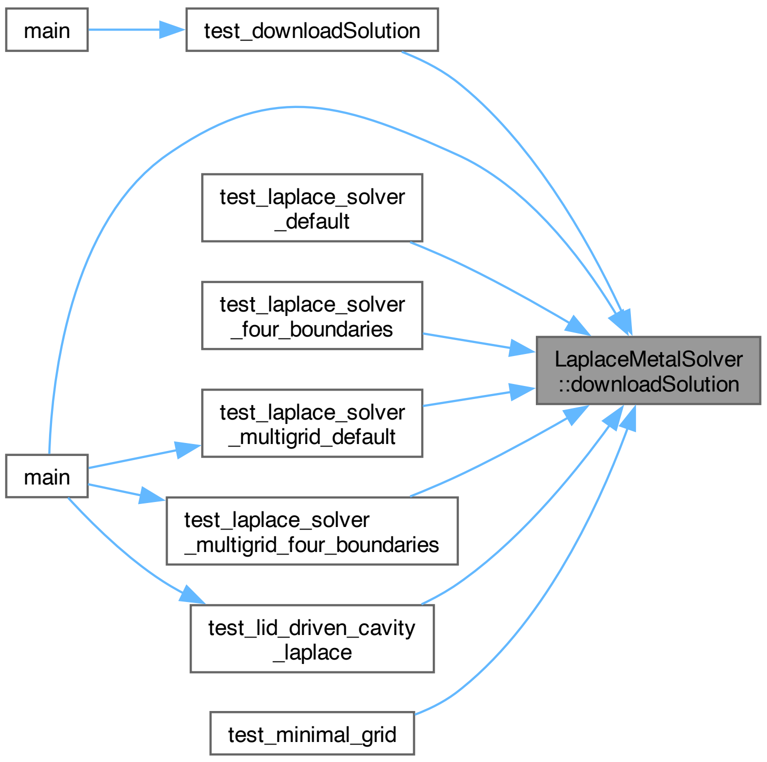
3.2.3.7 debugRestrictTest()

```
void LaplaceMetalSolver::debugRestrictTest ()
```

3.2.3.8 downloadSolution()

```
std::vector< float > LaplaceMetalSolver::downloadSolution () const
```

Here is the caller graph for this function:


main
test_downloadSolution
test_laplace_solver _default
test_laplace_solver _four_boundaries
test_laplace_solver _multigrid_default
main
test_laplace_solver _multigrid_four_boundaries
test_lid_driven_cavity _laplace
test_minimal_grid
LaplaceMetalSolver ::downloadSolution

3.2.3.9 operator=()

```
LaplaceMetalSolver & LaplaceMetalSolver::operator= (
             const LaplaceMetalSolver & )  [delete]
```

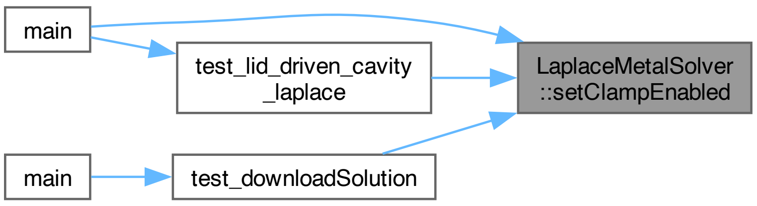
3.2.3.10 relativeTolerance()

```
float LaplaceMetalSolver::relativeTolerance () const  [inline]
```

3.2.3.11 setClampEnabled()

```
void LaplaceMetalSolver::setClampEnabled (
             bool e)  [inline]
```

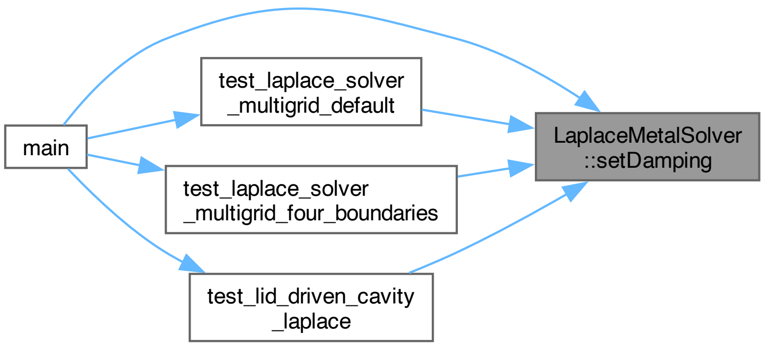
Here is the caller graph for this function:


main
test_lid_driven_cavity _laplace
LaplaceMetalSolver ::setClampEnabled
main
test_downloadSolution

3.2.3.12 setDamping()

```
void LaplaceMetalSolver::setDamping (
             float w)  [inline]
```

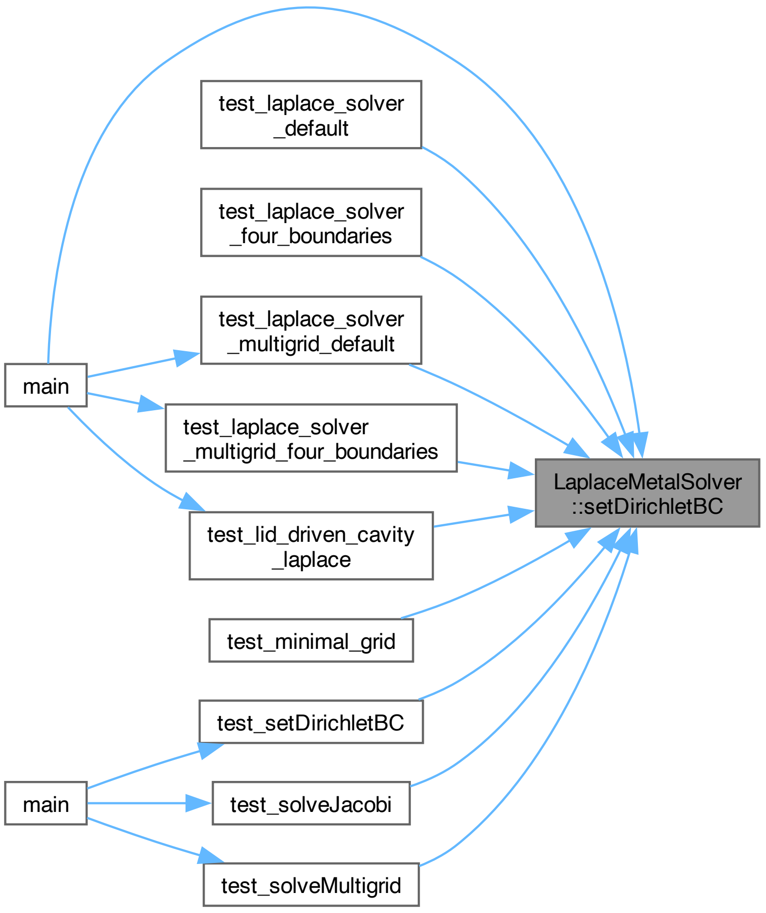
Here is the caller graph for this function:


test_laplace_solver _multigrid_default
main
LaplaceMetalSolver ::setDamping
test_laplace_solver _multigrid_four_boundaries
test_lid_driven_cavity _laplace

3.2.3.13 setDirichletBC()

```
void LaplaceMetalSolver::setDirichletBC (
            const std::vector< uint8_t > & mask,
            const std::vector< float > & values)
```

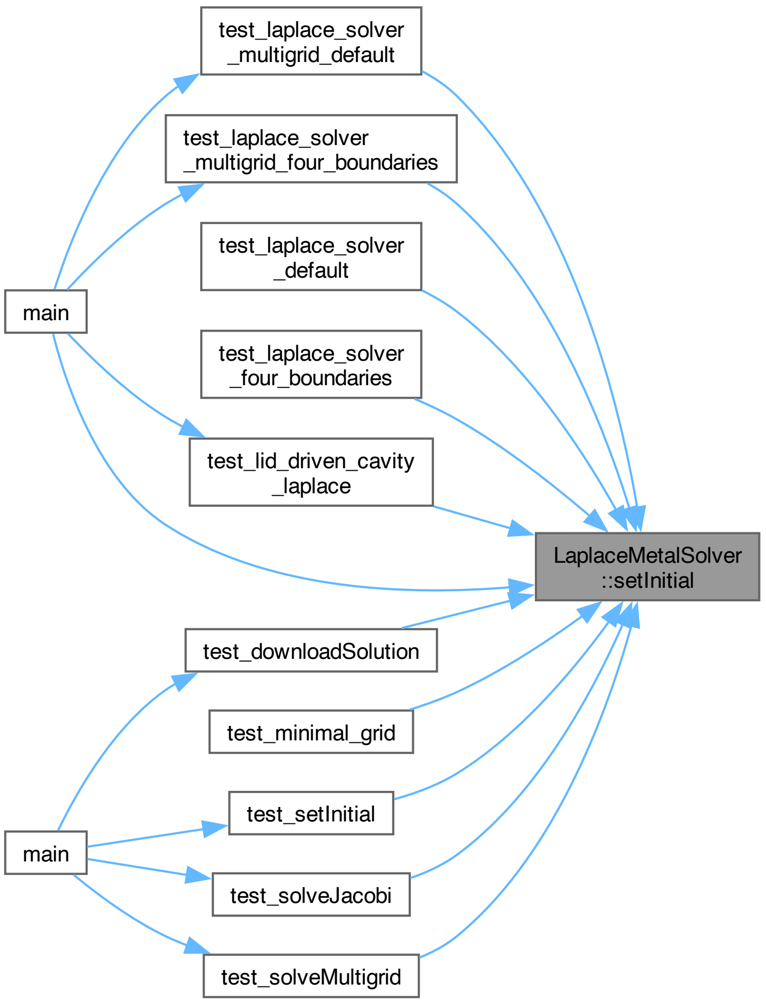
Here is the caller graph for this function:


test_laplace_solver _default
test_laplace_solver _four_boundaries
test_laplace_solver _multigrid_default
main
test_laplace_solver _multigrid_four_boundaries
LaplaceMetalSolver ::setDirichletBC
test_lid_driven_cavity _laplace
test_minimal_grid
test_setDirichletBC
main
test_solveJacobi
test_solveMultigrid

3.2.3.14 setInitial()

```
void LaplaceMetalSolver::setInitial (
            const std::vector< float > & u0)
```

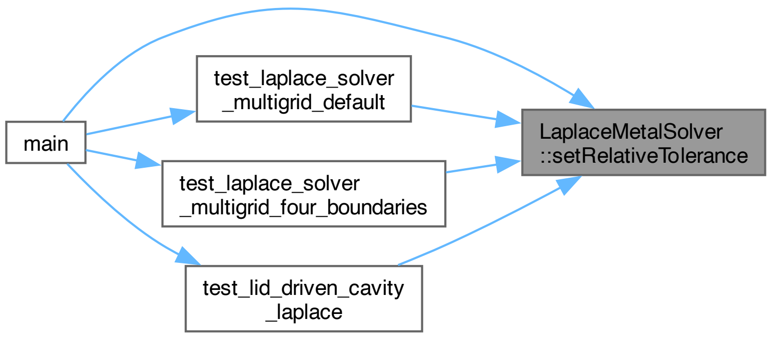
Here is the caller graph for this function:


test_laplace_solver _multigrid_default
test_laplace_solver _multigrid_four_boundaries
test_laplace_solver _default
test_laplace_solver _four_boundaries
test_lid_driven_cavity _laplace
main
LaplaceMetalSolver ::setInitial
test_downloadSolution
test_minimal_grid
test_setInitial
test_solveJacobi
test_solveMultigrid
main

3.2.3.15 setRelativeTolerance()

```
void LaplaceMetalSolver::setRelativeTolerance (
            float r)  [inline]
```

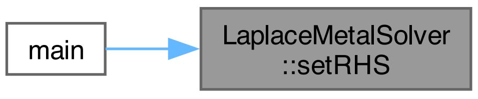
Here is the caller graph for this function:



3.2.3.16 setRHS()

```
void LaplaceMetalSolver::setRHS (
            const std::vector< float > & rhs)
```

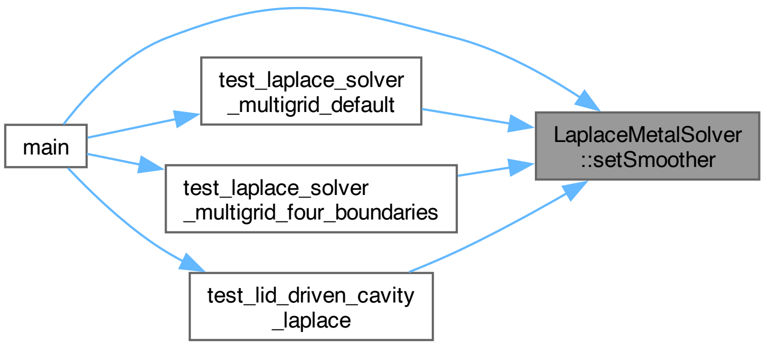
Here is the caller graph for this function:



3.2.3.17 setSmoother()

```
void LaplaceMetalSolver::setSmoother (
            Smoother s) [inline]
```

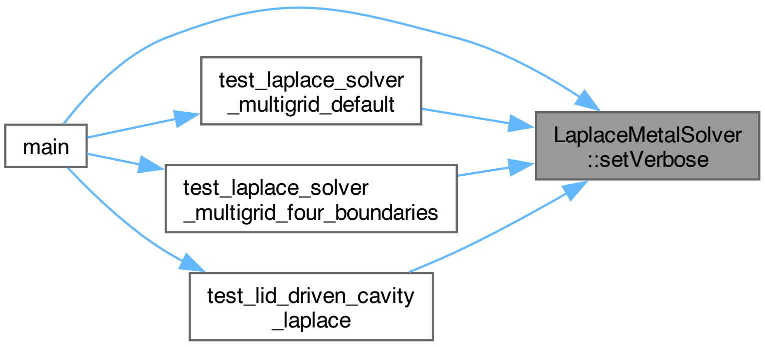
Here is the caller graph for this function:


main
test_laplace_solver _multigrid_default
test_laplace_solver _multigrid_four_boundaries
test_lid_driven_cavity _laplace
LaplaceMetalSolver ::setSmoother

3.2.3.18 setVerbose()

```
void LaplaceMetalSolver::setVerbose (
             bool v)  [inline]
```

Here is the caller graph for this function:


main
test_laplace_solver _multigrid_default
test_laplace_solver _multigrid_four_boundaries
test_lid_driven_cavity _laplace
LaplaceMetalSolver ::setVerbose

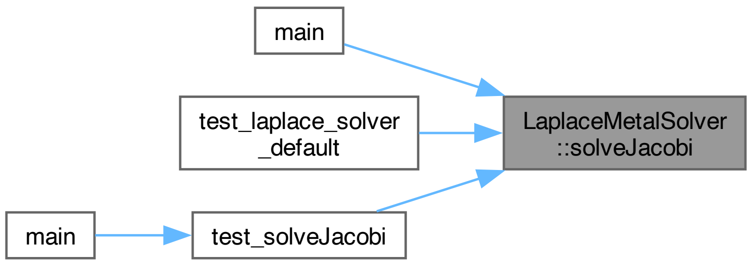
3.2.3.19 smoother()

```
Smoother LaplaceMetalSolver::smoother () const  [inline]
```

3.2.3.20 solveJacobi()

```
bool LaplaceMetalSolver::solveJacobi (
            uint32_t max_iters,
            float tol,
            uint32_t * out_iters = nullptr,
            float * residual_l2 = nullptr)
```

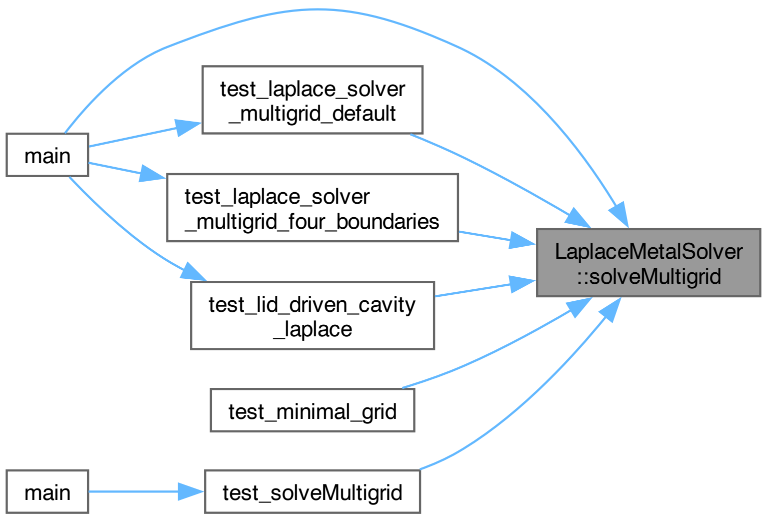
Here is the caller graph for this function:



3.2.3.21 solveMultigrid()

```
bool LaplaceMetalSolver::solveMultigrid (
            uint32_t max_vcycles,
            float tol,
            uint32_t nu1 = 3,
            uint32_t nu2 = 3,
            uint32_t coarse_iters = 30)
```

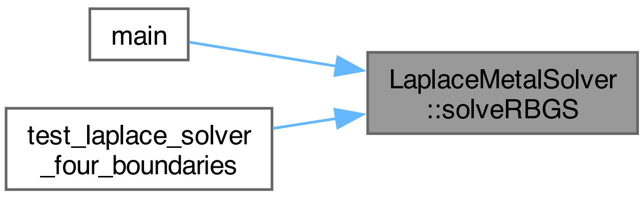
Here is the caller graph for this function:


main
test_laplace_solver _multigrid_default
test_laplace_solver _multigrid_four_boundaries
test_lid_driven_cavity _laplace
test_minimal_grid
main
test_solveMultigrid
LaplaceMetalSolver ::solveMultigrid

3.2.3.22 solveRBGS()

```
bool LaplaceMetalSolver::solveRBGS (
             uint32_t max_iters,
             float tol,
             uint32_t * out_iters = nullptr,
             float * residual_l2 = nullptr)
```

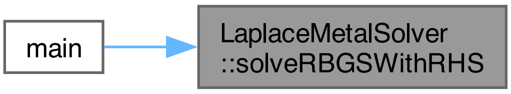
Here is the caller graph for this function:


main
test_laplace_solver _four_boundaries
LaplaceMetalSolver ::solveRBGS

3.2.3.23 solveRBGSWithRHS()

```
bool LaplaceMetalSolver::solveRBGSWithRHS (
             uint32_t max_iters,
             float tol,
             uint32_t * out_iters = nullptr,
             float * residual_l2 = nullptr)
```

Here is the caller graph for this function:



3.2.3.24 verbose()

```
bool LaplaceMetalSolver::verbose () const  [inline]
```

3.2.4 Member Data Documentation

3.2.4.1 levels_

```
std::vector<MGLevel> LaplaceMetalSolver::levels_
```

The documentation for this class was generated from the following files:

- metal/LaplaceMetalSolver.hpp
- metal/LaplaceMetalSolver.mm

3.3 LaplaceMetalSolver::MGLevel Struct Reference

```
#include <LaplaceMetalSolver.hpp>
```

Public Attributes

- uint32_t nx = 0
- uint32_t ny = 0
- float dx = 1.f
- float dy = 1.f
- void ∗ uA = nullptr
- void ∗ uB = nullptr
- void ∗ rhs = nullptr
- void ∗ bcMask = nullptr
- void ∗ bcVals = nullptr
- void ∗ uniforms = nullptr
- size_t fieldBytes = 0

3.3.1 Member Data Documentation

3.3.1.1 bcMask

```
void* LaplaceMetalSolver::MGLevel::bcMask = nullptr
```

3.3.1.2 bcVals

```
void* LaplaceMetalSolver::MGLevel::bcVals = nullptr
```

3.3.1.3 dx

```
float LaplaceMetalSolver::MGLevel::dx = 1.f
```

3.3.1.4 dy

```
float LaplaceMetalSolver::MGLevel::dy = 1.f
```

3.3.1.5 fieldBytes

```
size_t LaplaceMetalSolver::MGLevel::fieldBytes = 0
```

3.3.1.6 nx

```
uint32_t LaplaceMetalSolver::MGLevel::nx = 0
```

3.3.1.7 ny

```
uint32_t LaplaceMetalSolver::MGLevel::ny = 0
```

3.3.1.8 rhs

```
void* LaplaceMetalSolver::MGLevel::rhs = nullptr
```

3.3.1.9 uA

```
void* LaplaceMetalSolver::MGLevel::uA = nullptr
```

3.3.1.10 uB

```
void* LaplaceMetalSolver::MGLevel::uB = nullptr
```

3.3.1.11 uniforms

```
void* LaplaceMetalSolver::MGLevel::uniforms = nullptr
```

The documentation for this struct was generated from the following file:

- metal/LaplaceMetalSolver.hpp

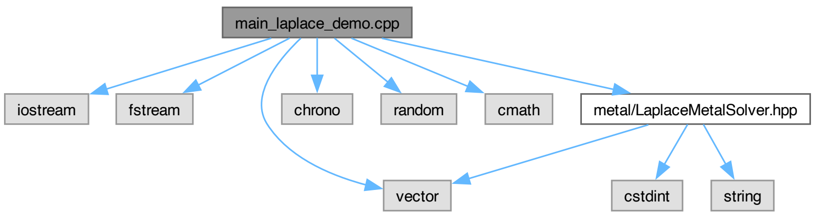
Chapter 4

File Documentation

4.1 main_laplace_demo.cpp File Reference

```
#include <iostream>
#include <fstream>
#include <vector>
#include <chrono>
#include <random>
#include <cmath>
#include "metal/LaplaceMetalSolver.hpp"
```

Include dependency graph for main_laplace_demo.cpp:



Functions

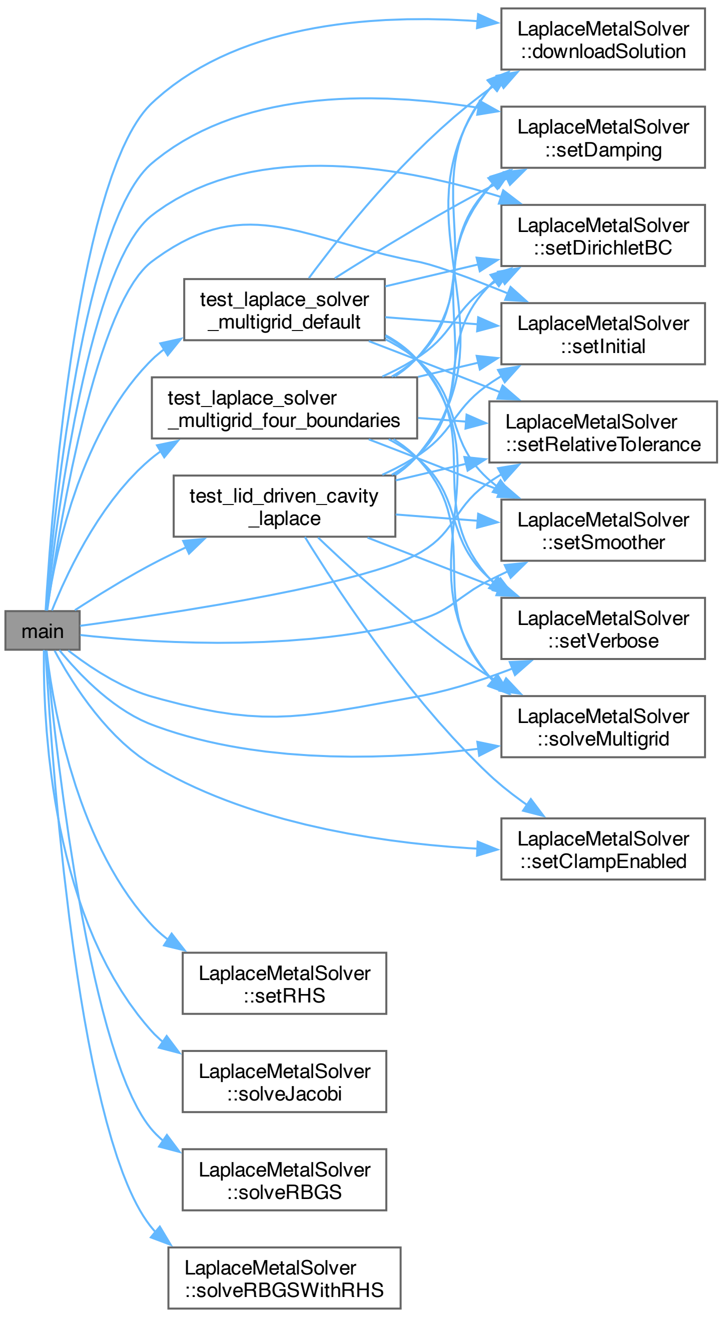
- void test_laplace_solver_four_boundaries ()
- void test_lid_driven_cavity_laplace ()
- void test_laplace_solver_default ()
- void test_laplace_solver_multigrid_default ()
- void test_minimal_grid ()
- void test_laplace_solver_multigrid_four_boundaries ()
- int main (int argc, char $**$argv)

4.1.1 Function Documentation

4.1.1.1 main()

```
int main (
            int argc,
            char ** argv)
```

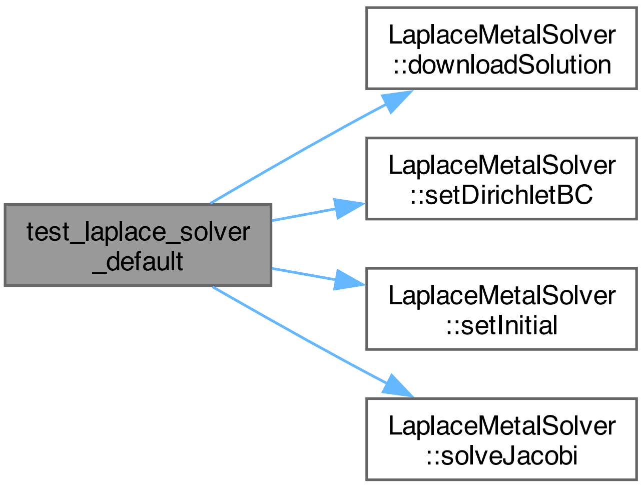
Here is the call graph for this function:


LaplaceMetalSolver ::downloadSolution
LaplaceMetalSolver ::setDamping
LaplaceMetalSolver ::setDirichletBC
test_laplace_solver _multigrid_default
LaplaceMetalSolver ::setInitial
test_laplace_solver _multigrid_four_boundaries
LaplaceMetalSolver ::setRelativeTolerance
test_lid_driven_cavity _laplace
LaplaceMetalSolver ::setSmoother
main
LaplaceMetalSolver ::setVerbose
LaplaceMetalSolver ::solveMultigrid
LaplaceMetalSolver ::setClampEnabled
LaplaceMetalSolver ::setRHS
LaplaceMetalSolver ::solveJacobi
LaplaceMetalSolver ::solveRBGS
LaplaceMetalSolver ::solveRBGSWithRHS

4.1.1.2 test_laplace_solver_default()

```
void test_laplace_solver_default ()
```

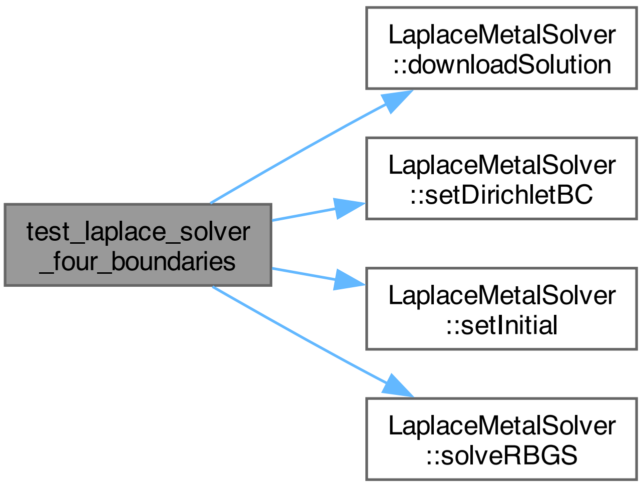
Here is the call graph for this function:


test_laplace_solver _default
LaplaceMetalSolver ::downloadSolution
LaplaceMetalSolver ::setDirichletBC
LaplaceMetalSolver ::setInitial
LaplaceMetalSolver ::solveJacobi

4.1.1.3 test_laplace_solver_four_boundaries()

```
void test_laplace_solver_four_boundaries ()
```

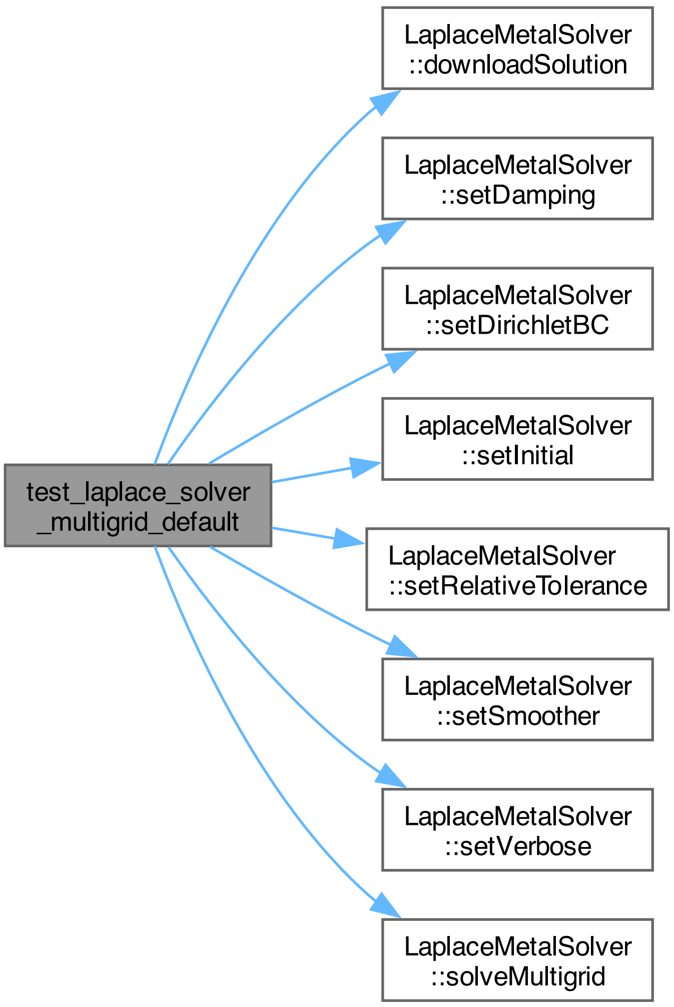
Here is the call graph for this function:


test_laplace_solver _four_boundaries
LaplaceMetalSolver ::downloadSolution
LaplaceMetalSolver ::setDirichletBC
LaplaceMetalSolver ::setInitial
LaplaceMetalSolver ::solveRBGS

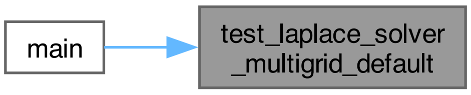
4.1.1.4 test_laplace_solver_multigrid_default()

```
void test_laplace_solver_multigrid_default ()
```

Here is the call graph for this function:


test_laplace_solver _multigrid_default
LaplaceMetalSolver ::downloadSolution
LaplaceMetalSolver ::setDamping
LaplaceMetalSolver ::setDirichletBC
LaplaceMetalSolver ::setInitial
LaplaceMetalSolver ::setRelativeTolerance
LaplaceMetalSolver ::setSmoother
LaplaceMetalSolver ::setVerbose
LaplaceMetalSolver ::solveMultigrid

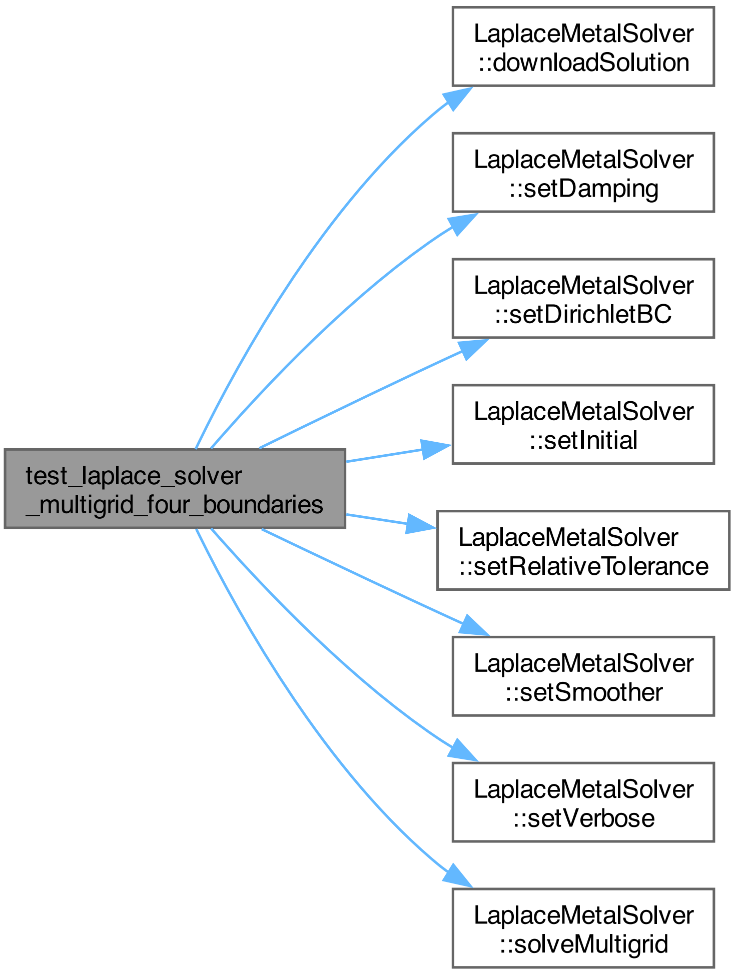
Here is the caller graph for this function:



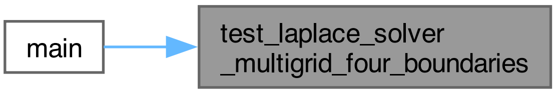
4.1.1.5 test_laplace_solver_multigrid_four_boundaries()

```
void test_laplace_solver_multigrid_four_boundaries ()
```

Here is the call graph for this function:



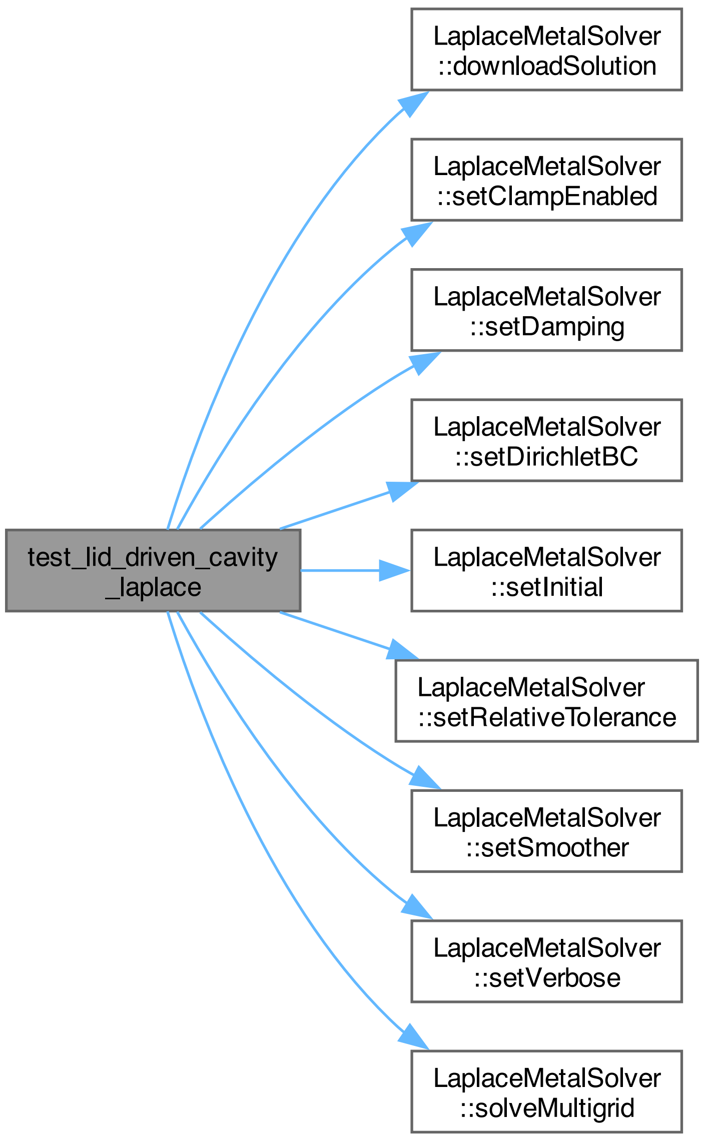
Here is the caller graph for this function:



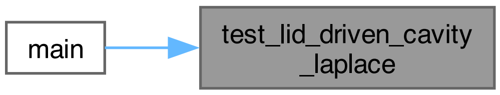
4.1.1.6 test_lid_driven_cavity_laplace()

```
void test_lid_driven_cavity_laplace ()
```

Here is the call graph for this function:


test_lid_driven_cavity_laplace
LaplaceMetalSolver::downloadSolution
LaplaceMetalSolver::setClampEnabled
LaplaceMetalSolver::setDamping
LaplaceMetalSolver::setDirichletBC
LaplaceMetalSolver::setInitial
LaplaceMetalSolver::setRelativeTolerance
LaplaceMetalSolver::setSmoother
LaplaceMetalSolver::setVerbose
LaplaceMetalSolver::solveMultigrid

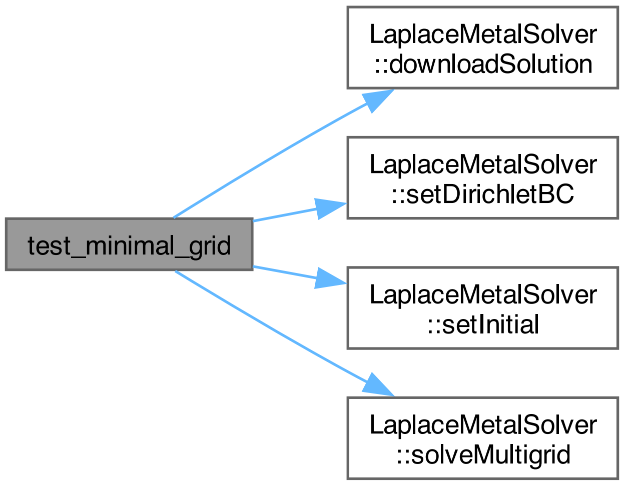
Here is the caller graph for this function:



4.1.1.7 test_minimal_grid()

```
void test_minimal_grid ()
```

Here is the call graph for this function:

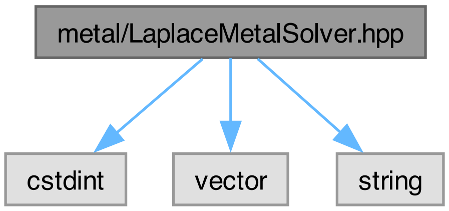

test_minimal_grid
LaplaceMetalSolver::downloadSolution
LaplaceMetalSolver::setDirichletBC
LaplaceMetalSolver::setInitial
LaplaceMetalSolver::solveMultigrid

4.2 metal/laplace_kernels.metal File Reference

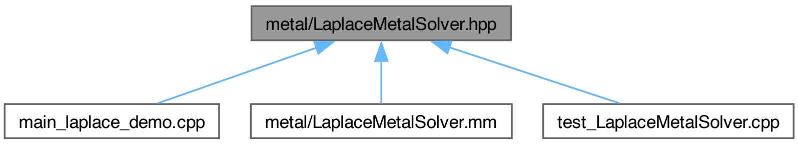
4.3 metal/LaplaceMetalSolver.hpp File Reference

```
#include <cstdint>
#include <vector>
```

`#include <string>`
Include dependency graph for LaplaceMetalSolver.hpp:



This graph shows which files directly or indirectly include this file:


metal/LaplaceMetalSolver.hpp
main_laplace_demo.cpp
metal/LaplaceMetalSolver.mm
test_LaplaceMetalSolver.cpp

Classes

- class LaplaceMetalSolver
- struct LaplaceMetalSolver::Desc
- struct LaplaceMetalSolver::MGLevel

4.4 LaplaceMetalSolver.hpp

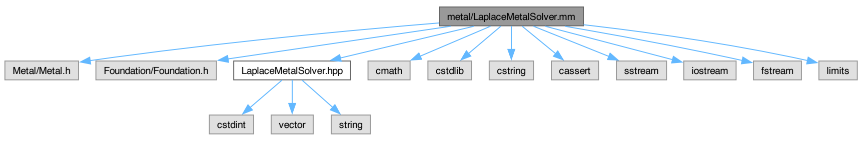
Go to the documentation of this file.

```
#pragma once
#include <cstdint>
#include <vector>
#include <string>

class LaplaceMetalSolver
{
public:
    enum class Smoother
    {
        Jacobi,
        RBGS
    };
    struct Desc
    {
        uint32_t nx = 0, ny = 0;
        float dx = 1.f, dy = 1.f;
    };

    struct MGLevel
    {
        uint32_t nx = 0, ny = 0;
        float dx = 1.f, dy = 1.f;
        // Solution/correction ping-pong
        void *uA = nullptr; // current
        void *uB = nullptr; // next
        // RHS / residual on this level
        void *rhs = nullptr;
        // Boundary data (mask=1 at domain boundary; values = nonhom on L0, zeros otherwise)
        void *bcMask = nullptr; // uint8_t
        void *bcVals = nullptr; // float
        // Uniforms for this level
        void *uniforms = nullptr;
        size_t fieldBytes = 0;
    };
    std::vector<MGLevel> levels_;

    LaplaceMetalSolver(const Desc &d, const char *metal_path = nullptr);
    ~LaplaceMetalSolver();

    void setInitial(const std::vector<float> &u0);
    void setDirichletBC(const std::vector<uint8_t> &mask,
                        const std::vector<float> &values);

    bool solveJacobi(uint32_t max_iters, float tol,
                     uint32_t *out_iters = nullptr,
                     float *residual_l2 = nullptr);

    // Single-level Red-Black Gauss-Seidel (in-place) solver.
    // Runs alternating red/black updates until residual L2 <= tol or max_iters reached.
    bool solveRBGS(uint32_t max_iters, float tol,
                   uint32_t *out_iters = nullptr,
                   float *residual_l2 = nullptr);

    std::vector<float> downloadSolution() const;

    // Optional: provide a right-hand side f for Poisson: -^2 u = f
    // Copies data into the finest level's rhs buffer.
    void setRHS(const std::vector<float> &rhs);

    // Single-level Red-Black Gauss-Seidel solve with RHS (Poisson form).
    // Uses rbgs_phase_rhs kernel and stops when L2 residual (rhs - Au) <= tol.
    bool solveRBGSWithRHS(uint32_t max_iters, float tol,
                          uint32_t *out_iters = nullptr,
                          float *residual_l2 = nullptr);

    // Toggle safety clamp to boundary range. Enable for Laplace (f=0). Disable for Poisson (f!=0).
    void setClampEnabled(bool e) { clampEnabled_ = e; }
    bool clampEnabled() const { return clampEnabled_; }

    LaplaceMetalSolver(const LaplaceMetalSolver &) = delete;
    LaplaceMetalSolver &operator=(const LaplaceMetalSolver &) = delete;

    // Optional: control verbosity of internal logging (default: false)
    void setVerbose(bool v) { verbose_ = v; }
    bool verbose() const { return verbose_; }

    // Optional: control Jacobi damping factor omega in (0,1]. Default: 0.7f
    void setDamping(float w)
    {
        damping_ = w;
        updateTopLevelUniforms_();
    }
    float damping() const { return damping_; }

    // Optional: choose the smoother used in multigrid (default: Jacobi)
    void setSmoother(Smoother s) { smoother_ = s; }
    Smoother smoother() const { return smoother_; }

    // Optional: relative residual stopping criterion for multigrid (res/res0 <= relTol)
    void setRelativeTolerance(float r) { relTol_ = r; }
    float relativeTolerance() const { return relTol_; }

    // Geometric Multigrid V-cycle solver.
    // max_vcycles: number of V-cycles
    // tol: stop if L2 residual on finest level <= tol
    // nu1/nu2: pre/post relaxations per level
    // coarse_iters: smoothing iterations on coarsest grid
    bool solveMultigrid(uint32_t max_vcycles, float tol,
                        uint32_t nu1 = 3, uint32_t nu2 = 3,
                        uint32_t coarse_iters = 30);

    // Debug: run a GPU vs CPU full-weighting restriction test
    // Fills the fine residual with a known pattern, runs restriction,
    // and reports element-wise differences (max abs diff printed).
    void debugRestrictTest();

    // Debug: run a GPU vs CPU bilinear prolongation test
    // Fills a coarse correction with a deterministic pattern, runs prolongation
    // (add) into fine grid and compares GPU result against CPU bilinear interpolation.
    void debugProlongTest();

    // Debug: run a GPU vs CPU residual test
    // Fills fine-level solution with a deterministic pattern, runs compute_residual_raw,
    // and compares GPU residuals to CPU finite-difference r = -(uxx+uyy).
    void debugResidualTest();

    // Debug: run a GPU vs CPU single Jacobi-with-RHS step
    // Fills u_old and rhs with deterministic patterns, runs jacobi_step_rhs once
    // and compares GPU u_new against CPU update formula.
    void debugJacobiRhsTest();

    // Debug: print per-level Uniforms and verify coarsening scaling
    void debugCheckUniforms();

private:
    void *device_ = nullptr;
    void *queue_ = nullptr;
    void *lib_ = nullptr;
    void *psoJacobi_ = nullptr;
    void *psoResidual_ = nullptr;
    void *psoApplyBC_ = nullptr;
    // Optional smoother pipelines
    void *psoRBGS_ = nullptr;    // rbgs_phase (homogeneous)
    void *psoRBGSRHS_ = nullptr; // rbgs_phase_rhs (with RHS)
    void *bufU0_ = nullptr;
    void *bufU1_ = nullptr;
    void *bufBCMask_ = nullptr;
    void *bufBCVals_ = nullptr;
    void *bufR2_ = nullptr;
    void *bufUniforms_ = nullptr;
    uint32_t nx_ = 0, ny_ = 0;
    float dx_ = 1, dy_ = 1;
    size_t fieldBytes_ = 0;
    // Extra pipelines for MG
    void *psoResidualRaw_ = nullptr; // compute_residual_raw
    void *psoRestrict_ = nullptr;    // restrict_full_weighting
    void *psoProlongAdd_ = nullptr;  // prolong_bilinear_add
    void *psoJacobiRHS_ = nullptr;   // jacobi_step_rhs
    void *psoZeroFloat_ = nullptr;   // set_zero_float
    void *psoClamp_ = nullptr;       // clamp_to_bounds

    bool compileLibraryFromFile_(const char *, std::string &);
    bool compileLibraryFromEmbedded_(std::string &);
    bool buildPipelines_(std::string &);
    bool ensureBuffers_();
    float computeResidualL2_();
    bool applyBC_();
    void swapFields_();
    void clampToBoundaryRange_();

    bool buildLevels_();   // allocate/build level hierarchy
    void destroyLevels_(); // free level buffers
    bool vcycle_(uint32_t nu1, uint32_t nu2, uint32_t coarse_iters);
    bool smoothJacobi_(size_t lev, uint32_t iters, bool use_rhs);
    bool smoothRBGS_(size_t lev, uint32_t iters, bool use_rhs);
    bool computeResidual_(size_t lev);       // writes levels_[lev].rhs = residual
    bool restrictDown_(size_t lev_from);     // rhs_{l+1} = R rhs_l
    bool prolongateAdd_(size_t lev_to_fine); // u_l += P e_{l+1}
    bool applyBCLevel_(size_t lev);          // enforce BCs on levels_[lev].uA
    bool zeroFloat_(void *buf, size_t lev);  // GPU zero
    float computeResidualL2WithRHS_();       // CPU reduction of ||rhs - A u|| on finest level

    // Config flags
    bool verbose_ = false;
    float damping_ = 2.0f / 3.0f;
    Smoother smoother_ = Smoother::Jacobi;
    float relTol_ = -1.0f;

    // Boundary extrema on finest level (for safety clamp)
    float bcMin_ = 0.0f;
    float bcMax_ = 0.0f;
    bool clampEnabled_ = true;

    // Helper to refresh omega in the top-level uniforms buffer
    void updateTopLevelUniforms_();

    // Residual metrics on finest level (level 0)
    struct ResidualMetrics
    {
        float l2;
        float l2_h;
        float linf;
        size_t n;
    };
    bool computeResidualMetrics0_(ResidualMetrics &out);
};
```

4.5 metal/LaplaceMetalSolver.mm File Reference

```
import <Metal/Metal.h>
import <Foundation/Foundation.h>
#include "LaplaceMetalSolver.hpp"
#include <cmath>
#include <cstdlib>
#include <cstring>
#include <cassert>
#include <sstream>
#include <iostream>
#include <fstream>
#include <limits>
```

Include dependency graph for LaplaceMetalSolver.mm:



Macros

- #define CREATE_PIPELINE(name, kernelName)

4.5.1 Macro Definition Documentation

4.5.1.1 CREATE_PIPELINE

```
#define CREATE_PIPELINE(
                name,
                kernelName)
```

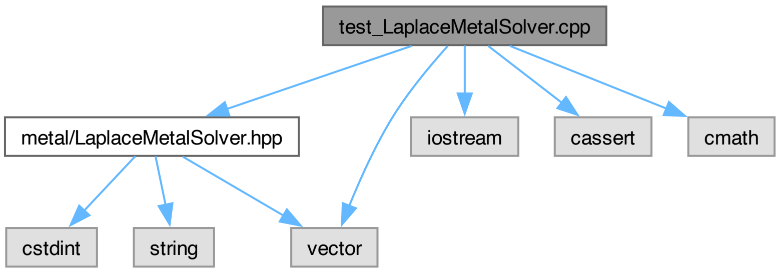
Value:

```
    do { \
    id<MTLFunction> func = [lib newFunctionWithName:@#kernelName]; \
    if (!func) { err = "Function '" #kernelName "' not found"; return false; } \
    id<MTLComputePipelineState> pso = [dev newComputePipelineStateWithFunction:func error:&error]; \
    if (error || !pso) { err = error ? std::string([[error localizedDescription] UTF8String]) : "Pipeline
      creation failed for " #kernelName; return false; } \
    name = (__bridge_retained void*)pso; \
} while(0)
```

4.6 test_LaplaceMetalSolver.cpp File Reference

```
#include "metal/LaplaceMetalSolver.hpp"
#include <iostream>
#include <vector>
#include <cassert>
#include <cmath>
```

Include dependency graph for test_LaplaceMetalSolver.cpp:



Macros

- #define TRACE_EXCEPTION(msg)

Functions

- void test_constructor ()
- void test_setInitial ()
- void test_setDirichletBC ()
- void test_solveJacobi ()
- void test_downloadSolution ()
- void test_solveMultigrid ()
- int main ()

4.6.1 Macro Definition Documentation

4.6.1.1 TRACE_EXCEPTION

```
#define TRACE_EXCEPTION(
            msg)
```

Value:

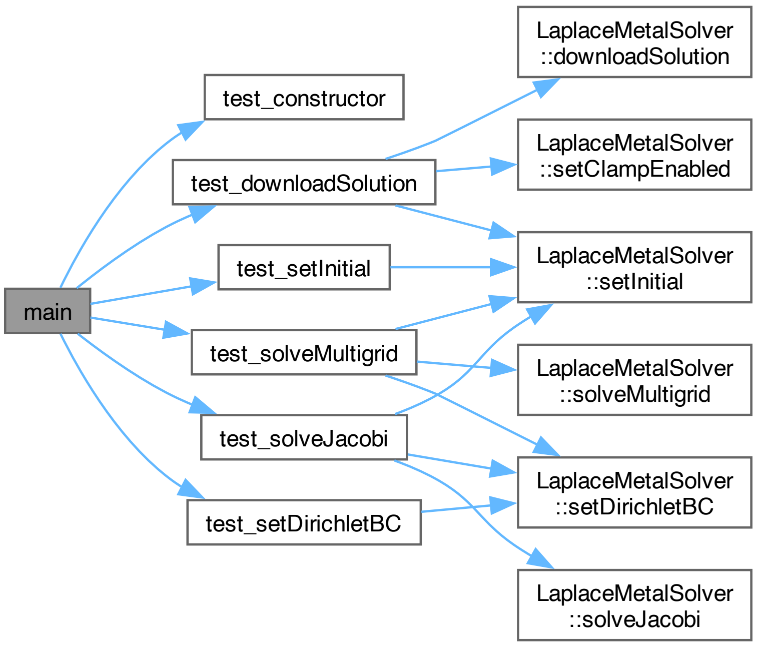
```
std::cerr « "[EXCEPTION] " « msg « std::endl;
```

4.6.2 Function Documentation

4.6.2.1 main()

```
int main ()
```

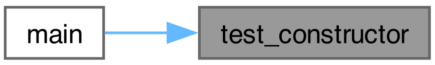
Here is the call graph for this function:


main
test_constructor
test_downloadSolution
test_setInitial
test_solveMultigrid
test_solveJacobi
test_setDirichletBC
LaplaceMetalSolver ::downloadSolution
LaplaceMetalSolver ::setClampEnabled
LaplaceMetalSolver ::setInitial
LaplaceMetalSolver ::solveMultigrid
LaplaceMetalSolver ::setDirichletBC
LaplaceMetalSolver ::solveJacobi

4.6.2.2 test_constructor()

```
void test_constructor ()
```

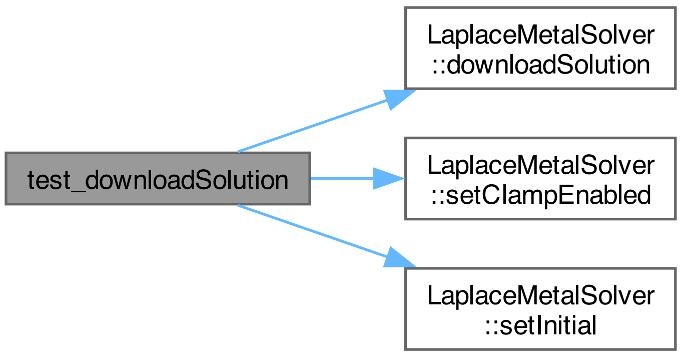
Here is the caller graph for this function:



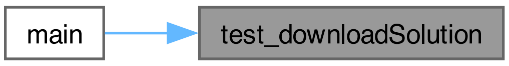
4.6.2.3 test_downloadSolution()

```
void test_downloadSolution ()
```

Here is the call graph for this function:


test_downloadSolution
LaplaceMetalSolver ::downloadSolution
LaplaceMetalSolver ::setClampEnabled
LaplaceMetalSolver ::setInitial

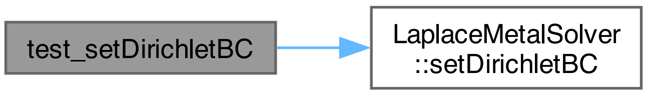
Here is the caller graph for this function:



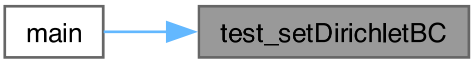
4.6.2.4 test_setDirichletBC()

```
void test_setDirichletBC ()
```

Here is the call graph for this function:



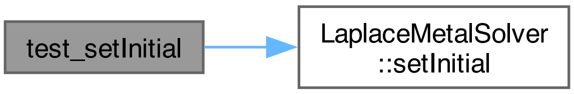
Here is the caller graph for this function:



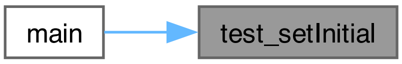
4.6.2.5 test_setInitial()

```
void test_setInitial ()
```

Here is the call graph for this function:



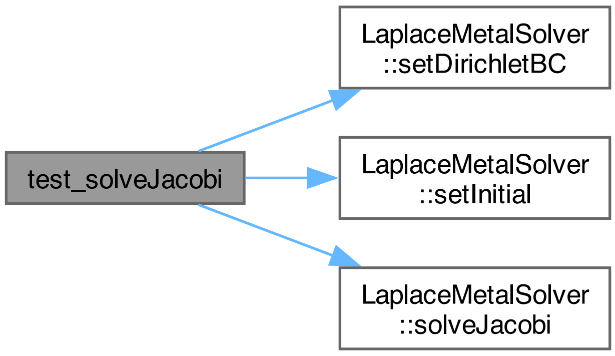
Here is the caller graph for this function:



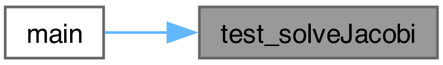
4.6.2.6 test_solveJacobi()

```
void test_solveJacobi ()
```

Here is the call graph for this function:


LaplaceMetalSolver ::setDirichletBC
test_solveJacobi
LaplaceMetalSolver ::setInitial
LaplaceMetalSolver ::solveJacobi

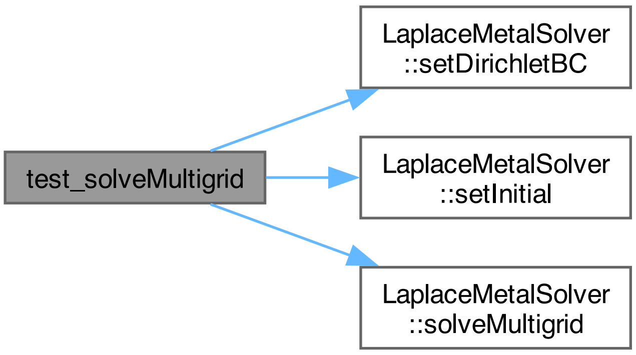
Here is the caller graph for this function:



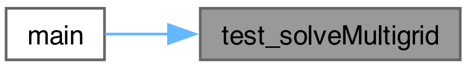
4.6.2.7 test_solveMultigrid()

```
void test_solveMultigrid ()
```

Here is the call graph for this function:


LaplaceMetalSolver ::setDirichletBC
test_solveMultigrid
LaplaceMetalSolver ::setInitial
LaplaceMetalSolver ::solveMultigrid

Here is the caller graph for this function:


main
test_solveMultigrid