OpenMP

Stony Brook University AMD Lawrence Livermore National Laboratory

Direct GPU Compilation and Execution for Host Applications with OpenMP Parallelism

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Host OpenMP Application

```
extern int foo(int a, int b);

int main(int argc, char *argv[]) {
  FILE *fp = fopen("data.txt", "r");
#pragma omp parallel for
  for (int i = 0; i < n; ++i)
    c[i] = foo(a[i], b[i]);
  return 0;
}
```

Port to CUDA

- kernel entry point
- device function
- index calculation
- memory mapping
- kernel launch

```
extern __device__ int foo(int a, int b);
__global__ void kernel(int *a, int *b, int *c) {
  int i = blockId.x * blockDim.x + threadId.x;
  c[i] = foo(a[i], b[i]);
}
int main(int argc, char *argv[]) {
  FILE *fp = fopen("data.txt", "r");
  int *da, *db, *dc;
  cudaMemcpy(da, a, ...);
  cudaMemcpy(db, b, ...);
  cudaMemcpy(dc, c, ...);
  kernel<<<...>>>(da, db, dc);
  return 0;
}
```

Port to OpenMP Offloading

- kernel entry point
- ~~device function~~
- ~~index calculation~~
- memory mapping
- kernel launch

```
extern int foo(int a, int b);

int main(int argc, char *argv[]) {
  FILE *fp = fopen("data.txt", "r");
#pragma omp target teams distribute parallel for\
        map(to: a[n], b[n]) map(from: c[n])
  for (int i = 0; i < n; ++i)
    c[i] = foo(a[i], b[i]);
  return 0;
}
```

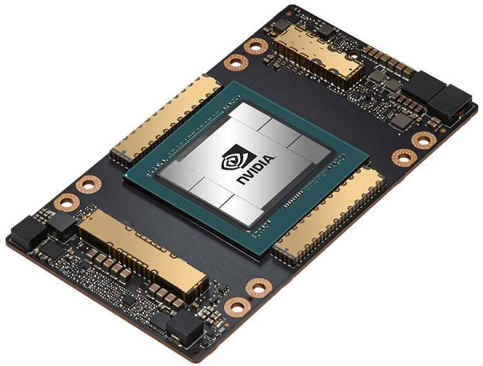
What If I Don’t Want to Port?

Can I just do something like…?

```
$ clang -f”run-on-gpu” my_app.c -o exec_on_gpu
```

and then

```
$ ./exec_on_gpu
```



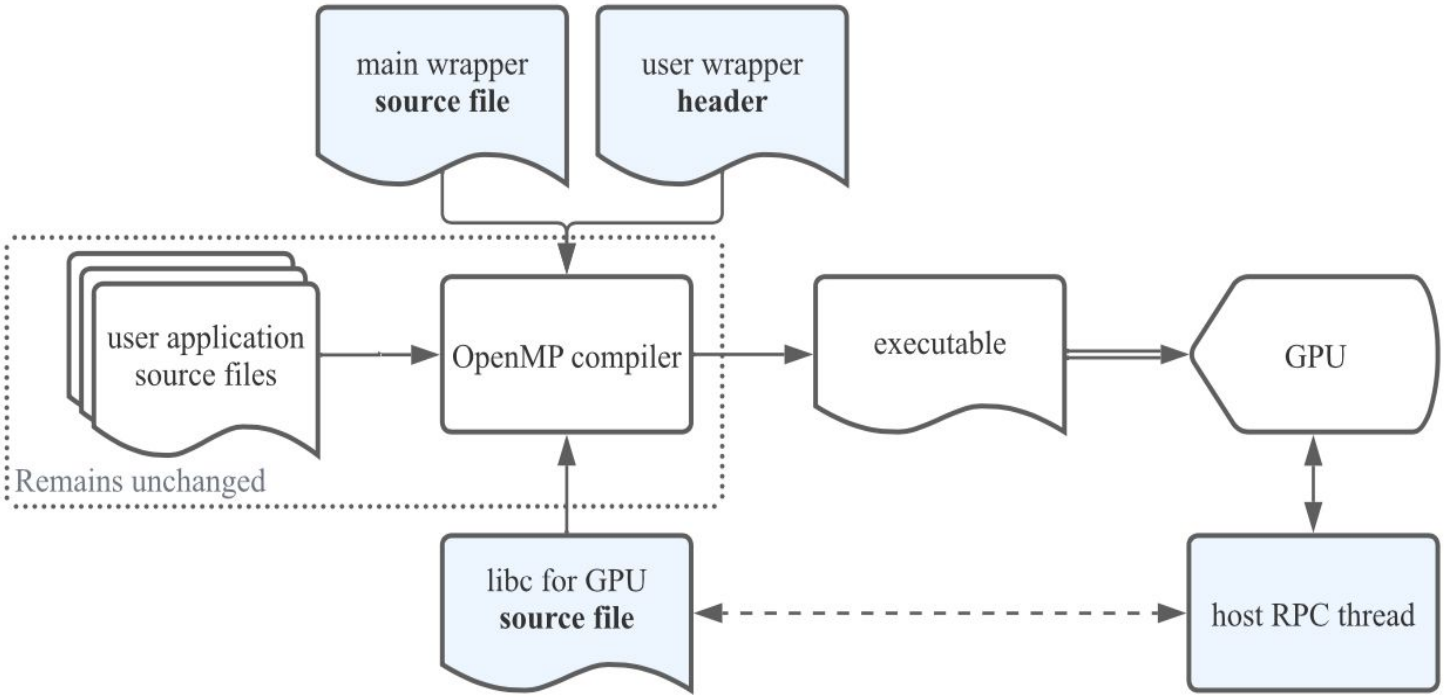
What Do We Need?

- device function
- kernel entry point
- ~~memory mapping~~
- ~~index calculation~~
- kernel launch
- library functions


```
extern int foo(int a, int b);

int main(int argc, char *argv[]) {
  FILE *fp = fopen("data.txt", "r");
#pragma omp parallel for
  for (int i = 0; i < n; ++i)
    c[i] = foo(a[i], b[i]);
  return 0;
}
```

Direct GPU Compilation



User Wrapper Header

```
#pragma omp begin declare target device_type(nohost)
int g;
void foo();
#pragma omp end declare target
```

User Wrapper Header

```
// UserWrapper.h
#pragma omp begin declare target device_type(nohost)
// <eof>
```

```
$ clang -include UserWrapper.h -c <user source files> ...
```

User Wrapper Header

```
#pragma omp begin declare target device_type(nohost)
extern int foo(int a, int b);

int main(int argc, char *argv[]) {
  FILE *fp = fopen("data.txt", "r");
#pragma omp parallel for
  for (int i = 0; i < n; ++i)
    c[i] = foo(a[i], b[i]);
  return 0;
}
#pragma omp end declare target
```

Main Wrapper

```
extern int __user_main(int, char *[]);

int main(int argc, char *argv[]) {
#pragma omp target enter data map(to: argv[:argc])

  for (int I = 0; I < argc; ++I) {
    size_t Len = strlen(argv[I]);
#pragma omp target enter data map(to: argv[I][:Len])
  }

  int Ret;
#pragma omp target teams num_teams(1) thread_limit(1024) map(from: Ret)
  { Ret = __user_main(argc, argv); }
  return Ret;
}
```

Kernel Entry Point

```
// UserWrapper.h
#pragma omp begin declare target device_type(nohost)

int main(int, char *[]) asm("__user_main");
// <eof>
```

Teams and num_teams(1)?

```
extern int __user_main(int, char *[]);

int main(int argc, char *argv[]) {
#pragma omp target enter data map(to: argv[:argc])

  for (int I = 0; I < argc; ++I) {
    size_t Len = strlen(argv[I]);
#pragma omp target enter data map(to: argv[I][:Len])
  }

  int Ret;
#pragma omp target teams num_teams(1) thread_limit(1024) map(from: Ret)
  { Ret = __user_main(argc, argv); }
  return Ret;
}
```

OpenMP Execution Model

```
void foo() {

  {
    /* region 1 */
#pragma omp parallel
    { /* region 2 */ }
    /* region 3 */
  }
}
```

OpenMP Execution Model

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void foo() {

  {
    /* region 1 */
#pragma omp parallel
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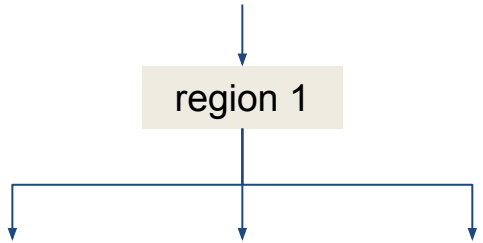
    /* region 3 */
  }
}
```

region 1

OpenMP Execution Model

```
void foo() {

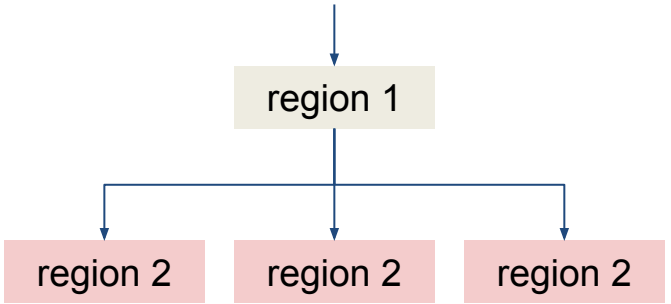
  {
    /* region 1 */
#pragma omp parallel
    { /* region 2 */ }
    /* region 3 */
  }
}
```



OpenMP Execution Model

```
void foo() {

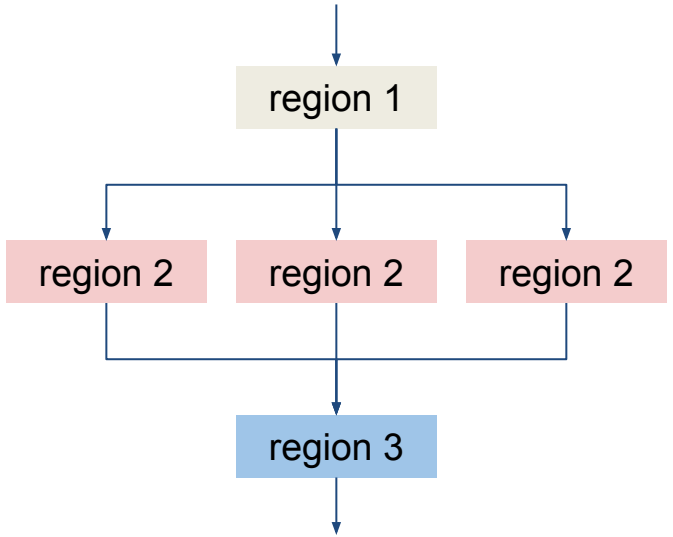
  {
    /* region 1 */
#pragma omp parallel
    { /* region 2 */ }
    /* region 3 */
  }
}
```



OpenMP Execution Model

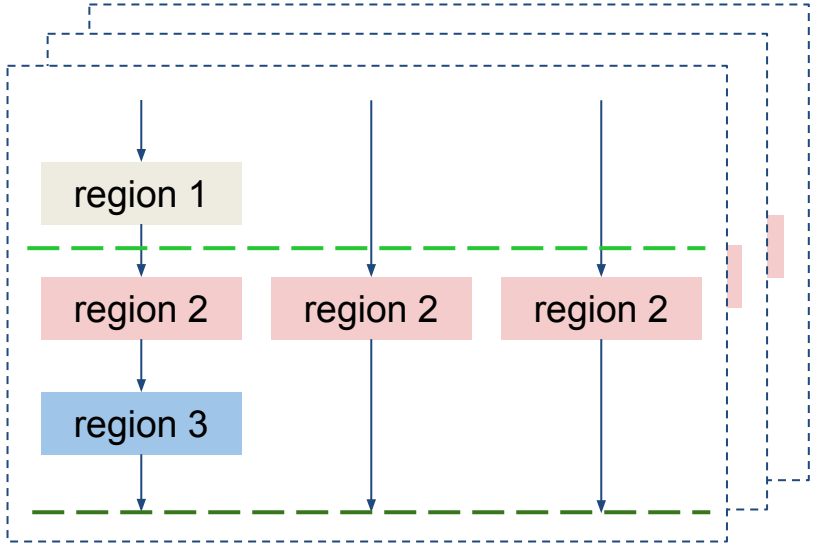
```
void foo() {

   {
     /* region 1 */
#pragma omp parallel
     { /* region 2 */ }
     /* region 3 */
   }
}
```



OpenMP Execution Model

```
void foo() {
#pragma omp target teams num_teams(N)
   {
     /* region 1 */
#pragma omp parallel
     { /* region 2 */ }
     /* region 3 */
   }
}
```



Standard C library

1) Memory-related functionality, e.g., `malloc` and `free`
2) Utilities, such as `strcmp`, `atof`, `atoi`, and `memcpy`
3) I/O access via `fread`, `fprintf`, and similar functions

Standard C library

1) Memory-related functionality, e.g., `malloc` and `free`
   - GPU support varies among vendors
   - Implemented custom dynamic heap allocation
2) Utilities, such as `strcmp`, `atof`, `atoi`, and `memcpy`
3) I/O access via `fread`, `fprintf`, and similar functions

Standard C library

1) Memory-related functionality, e.g., `malloc` and `free`
2) Utilities, such as `strcmp`, `atof`, `atoi`, and `memcpy`
   - Implemented in a device library linked into the application
3) I/O access via `fread`, `fprintf`, and similar functions

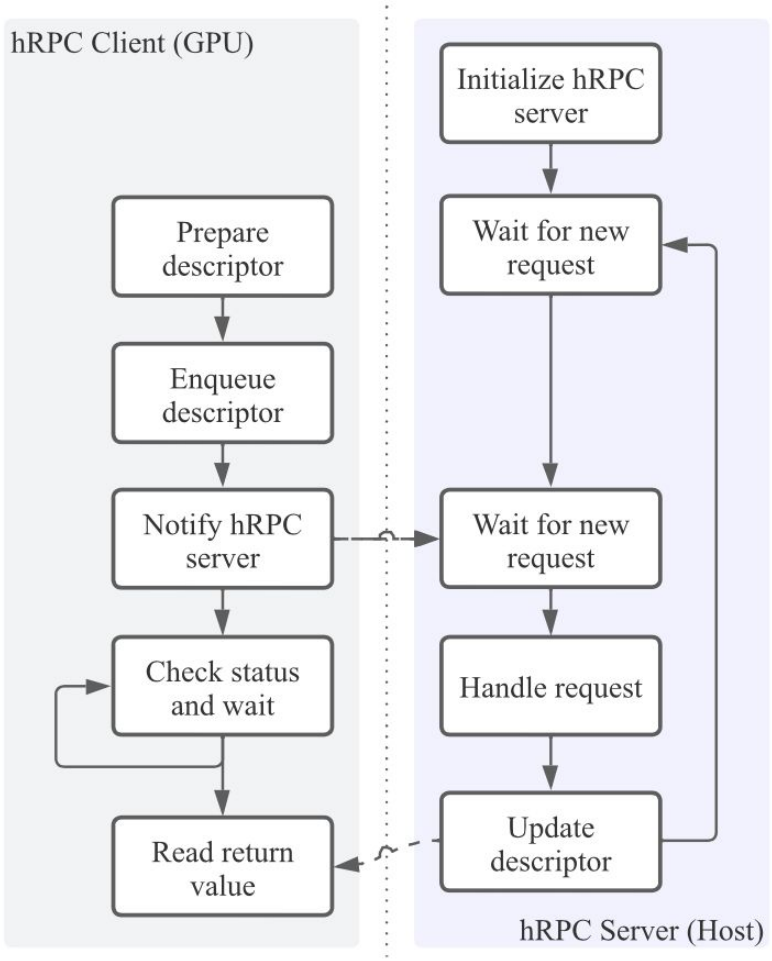
Standard C library

1) Memory-related functionality, e.g., `malloc` and `free`
2) Utilities, such as `strcmp`, `atof`, `atoi`, and `memcpy`
3) I/O access via `fread`, `fprintf`, and similar functions
   - Implemented via host remote procedure call (RPC)

Host RPC

Synchronous, stateless client-server protocol:

GPU (client) sends requests to host (server) and waits for completion



Example: Implement of fopen

```
FILE *fopen(const char *filename, const char *mode) {
  HostRPCDescriptorWrapper Wrapper(ID_fopen, 2);
  if (!Wrapper.isValid())
    return nullptr;

  auto Len1 = strlen(filename) + 1;
  auto Len2 = strlen(mode) + 1;

  HostRPCObject<const char *> FileName(Len1);
  HostRPCObject<const char *> Mode(Len2);

  FileName.copyFrom((void *)filename, Len1);
  Mode.copyFrom((void *)mode, Len2);

  Wrapper.addArg(FileName.get(), ARG_POINTER, Len1);
  Wrapper.addArg(Mode.get(), ARG_POINTER, Len2);

  if (!Wrapper.sendAndWait())
    return nullptr;
  return Wrapper.getReturnValue<FILE *>();
}
```

```
bool handle_fopen(HostRPCDescriptor &SD) {
  ArgumentExtractor AE(SD);

  auto *FileName = AE.getArg<const char *>(0);
  auto *Mode = AE.getArg<const char *>(1);

  FILE *F = fopen(FileName, Mode);
  if (F == nullptr)
    return false;

  SD.ReturnValue = (void *)F;
  return true;
}
```

Putting Together

```
$ clang -include UserWrapper.h
        -fopenmp --offload-arch=<arch>
        -c <user source files>

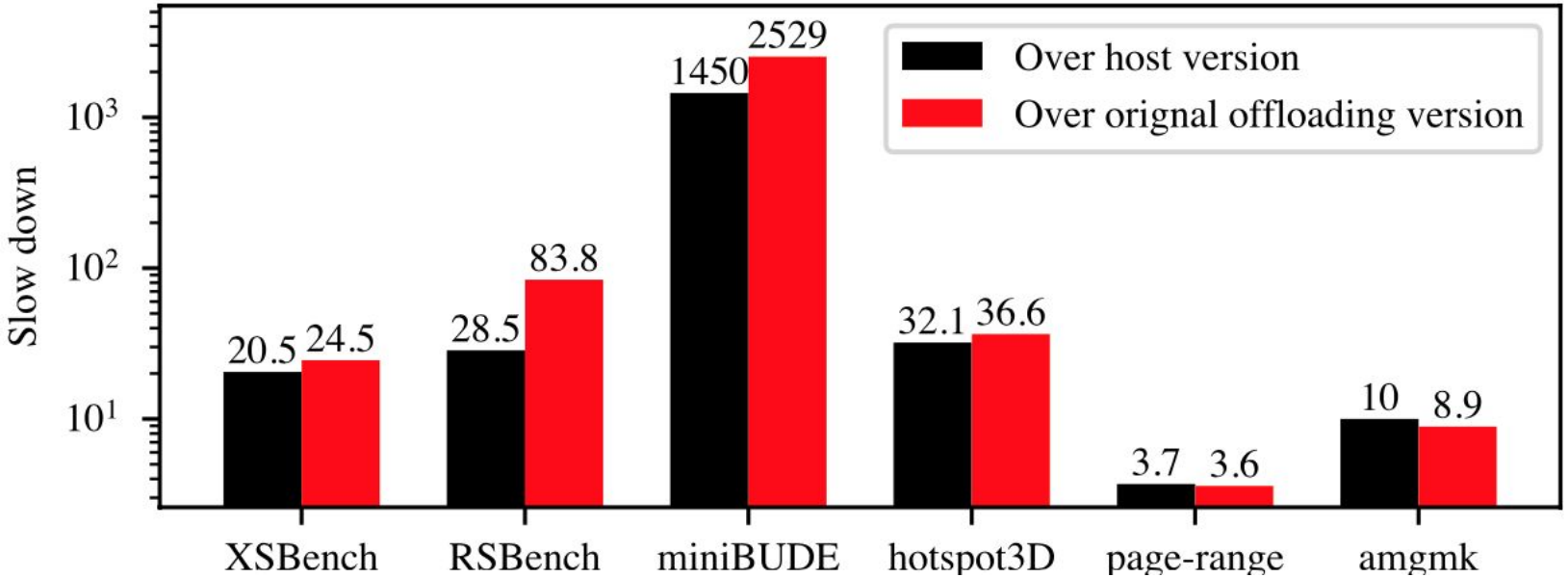
$ clang -c <path to>/Main.c -o __Main.o
        -fopenmp --offload-arch=<arch> -fopenmp-offload-mandatory

$ clang -fopenmp --offload-arch=<arch>
        __Main.o <other object files>
        -o <exec name>
```

Limitations

- Arbitrary library functions, including C++ STL
- Variadic functions
- Single team execution

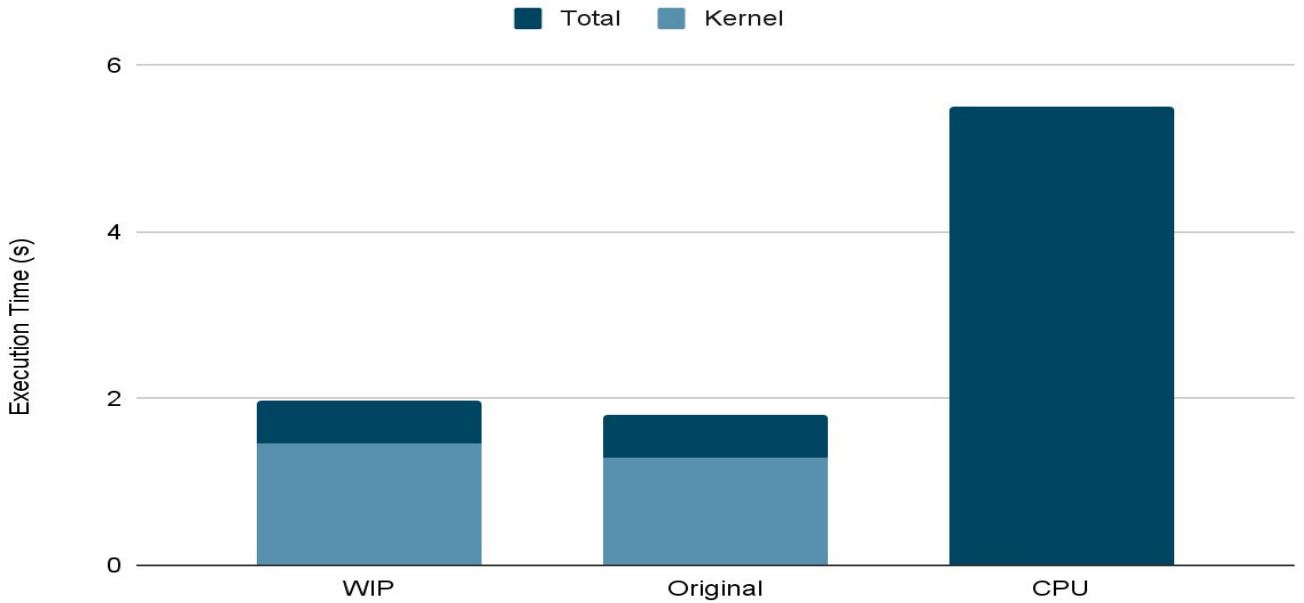
Performance Results



Lift the Limitations

- Support arbitrary library functions and variadic functions
  - Use new link time optimization pass
- Single team execution (performance issue)
  - Use multiple teams if a parallel region semantically allows it
    - XSBench can get back the performance of the actual computation part
  - If not, use “large team” that can have more than 1024 threads

New XSBench Result



Summary

- A user-transparent infrastructure that can compile the entire user program to have it directly running on GPUs.
  - Without the need to change the compiler.
- All the limitations and performance issues are being solved in our new prototype.

LibC for GPU

- LLVM libc officially supports GPU (partially yet)!
  - https://libc.llvm.org/gpu_mode.html
  - Basic device functions that do not require host are supported on the device.
    - `ctype.h` and `string.h`

Credit: Joseph Huber

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FAQ

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What's the point of doing it?

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Why not just replacing pragmas?

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FAQ

Do you support XXX?


THANK
YOU