Architecture-aware Automatic Computation Offload for Native Applications

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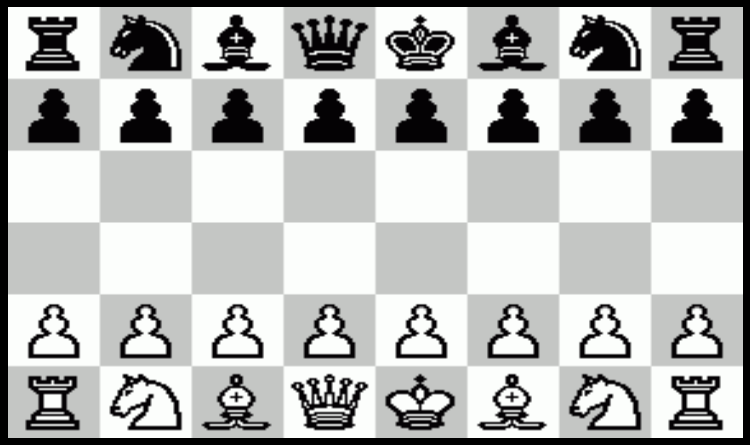
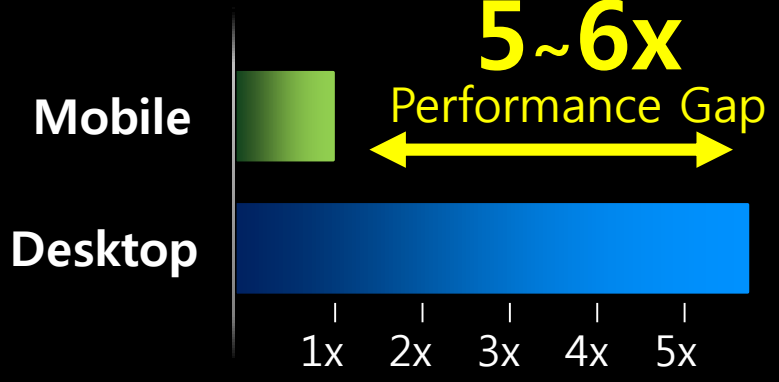
Kyung-Ah Chang*, Hyogun Lee*, and Hanjun Kim.

POSTECH / Samsung Electronics*

Mobile devices are slow

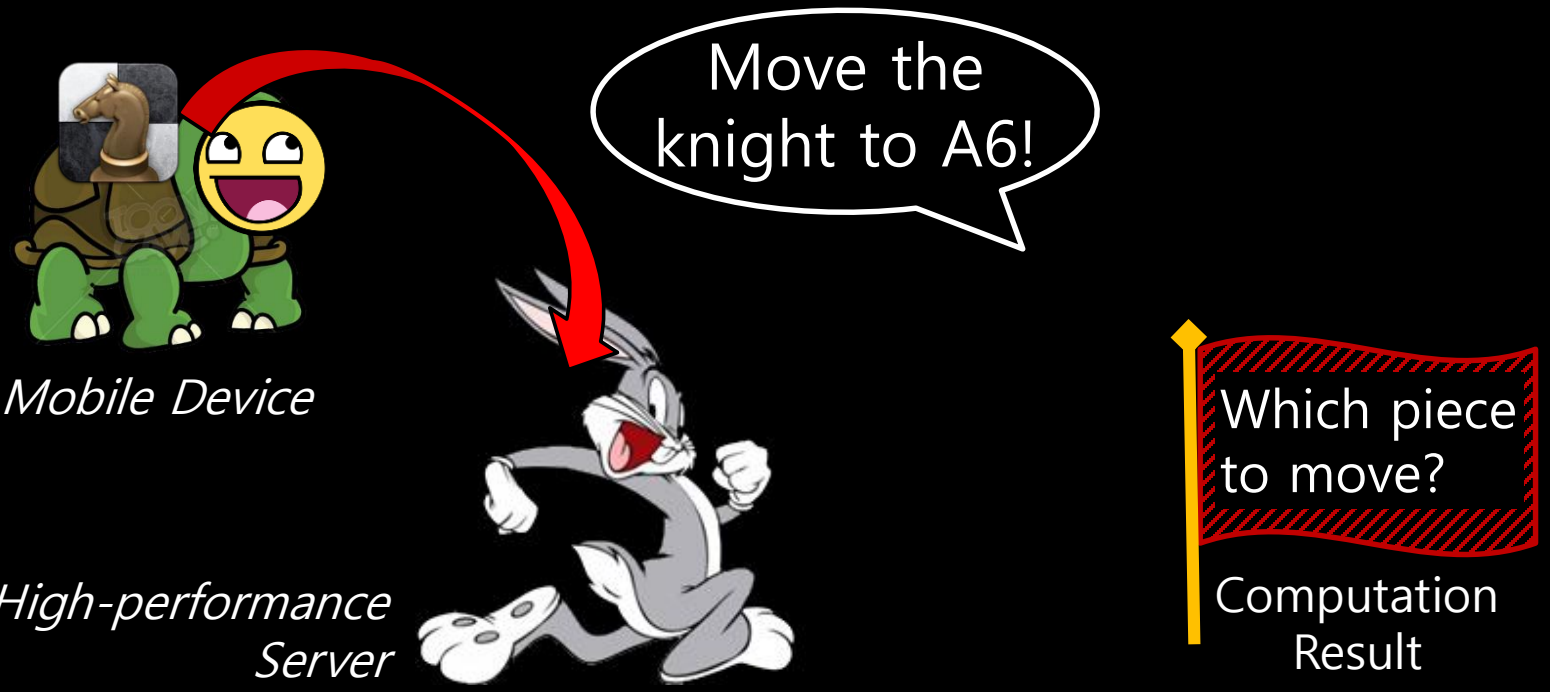
```
void runGame () {
  while (!gameover) {
    Move mv;

    /* User Inputs */
    mv = getPlayerTurn ();
    pieces[mv.tar] = mv.to;

    /* Heavy Computation */
    mv = getAITurn ();
    pieces[mv.tar] = mv.to;
  }
}
```



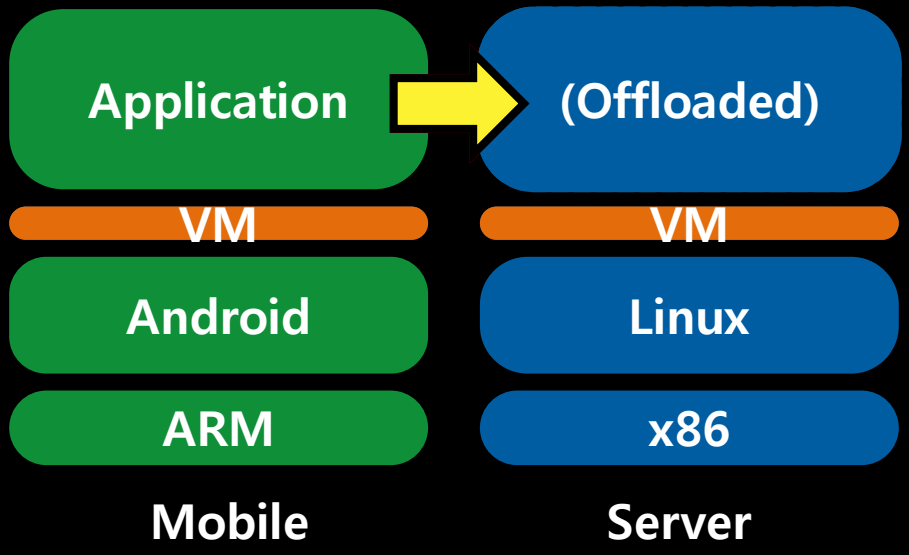


Chess Movement Computation

Offloading can boost your mobile device!

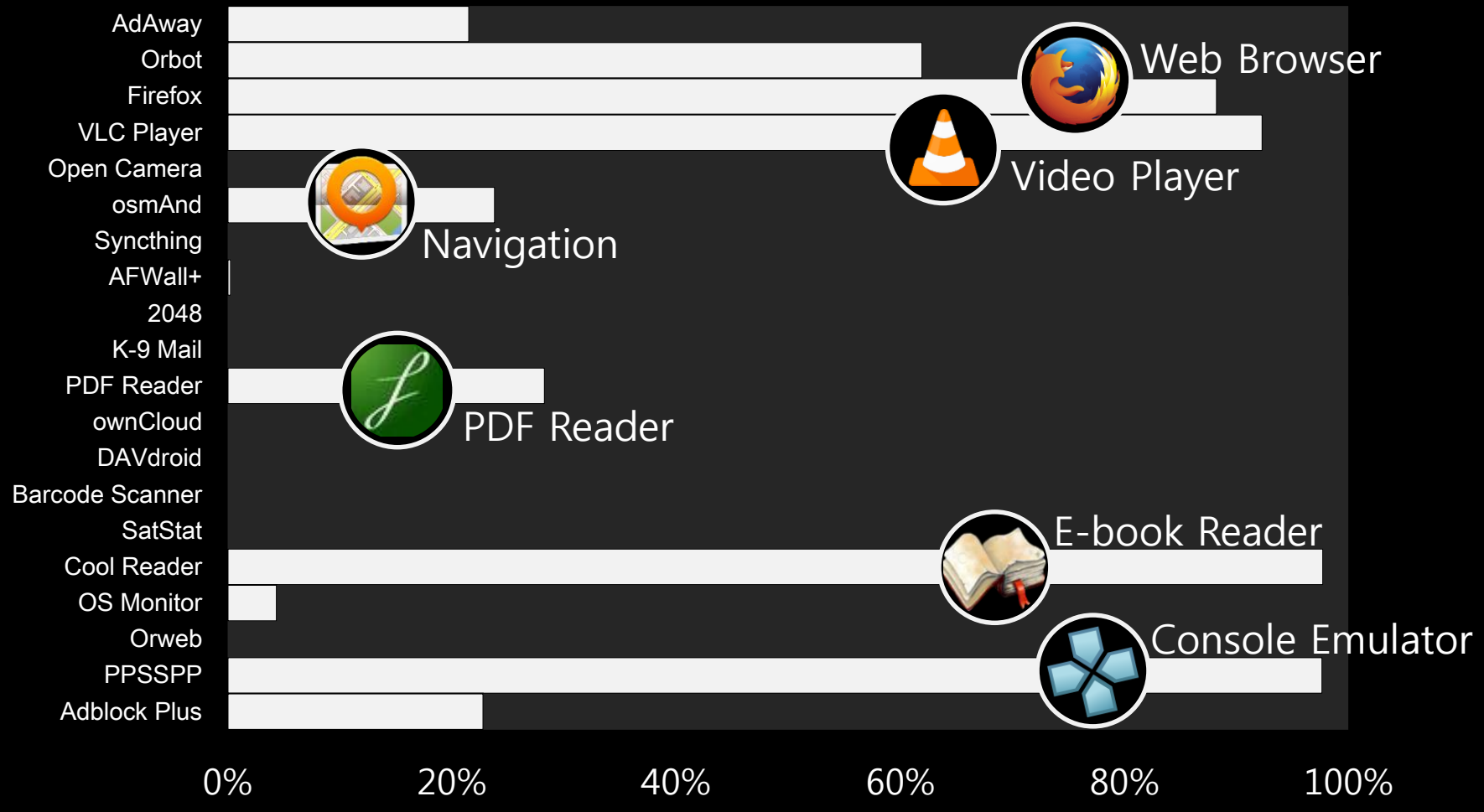


Most offloading systems are based on VMs.

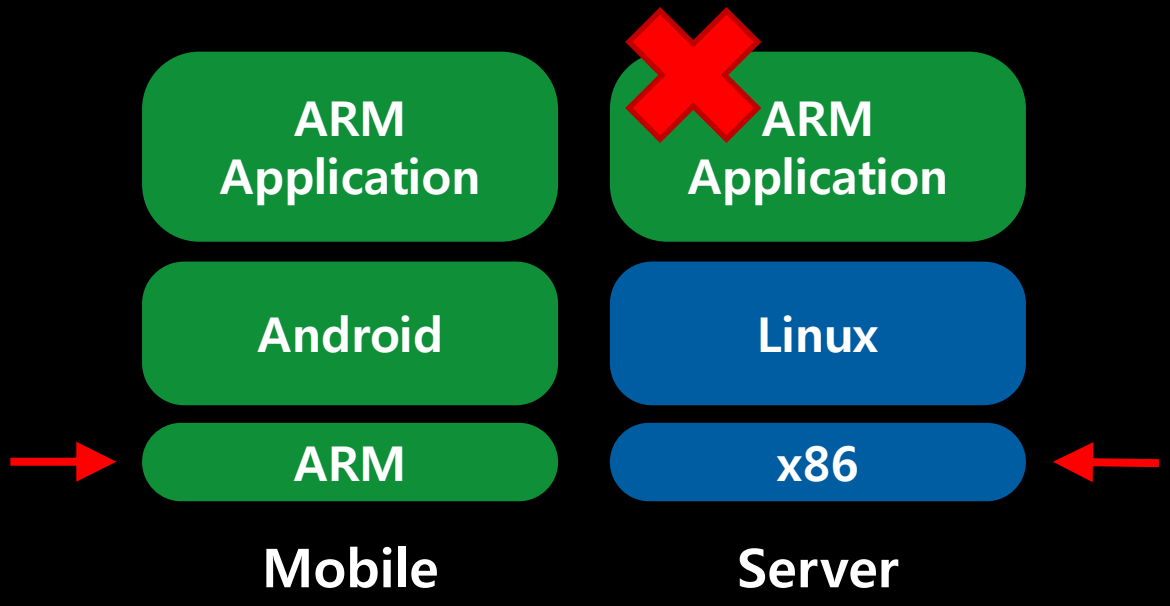


CloneCloud (EuroSys`11), **MAUI** (MobiSys`10), **CMCloud** (CCGrid`14)

Native Code Execution Time of Top 20 Android Applications



Challenges in offloading native workloads

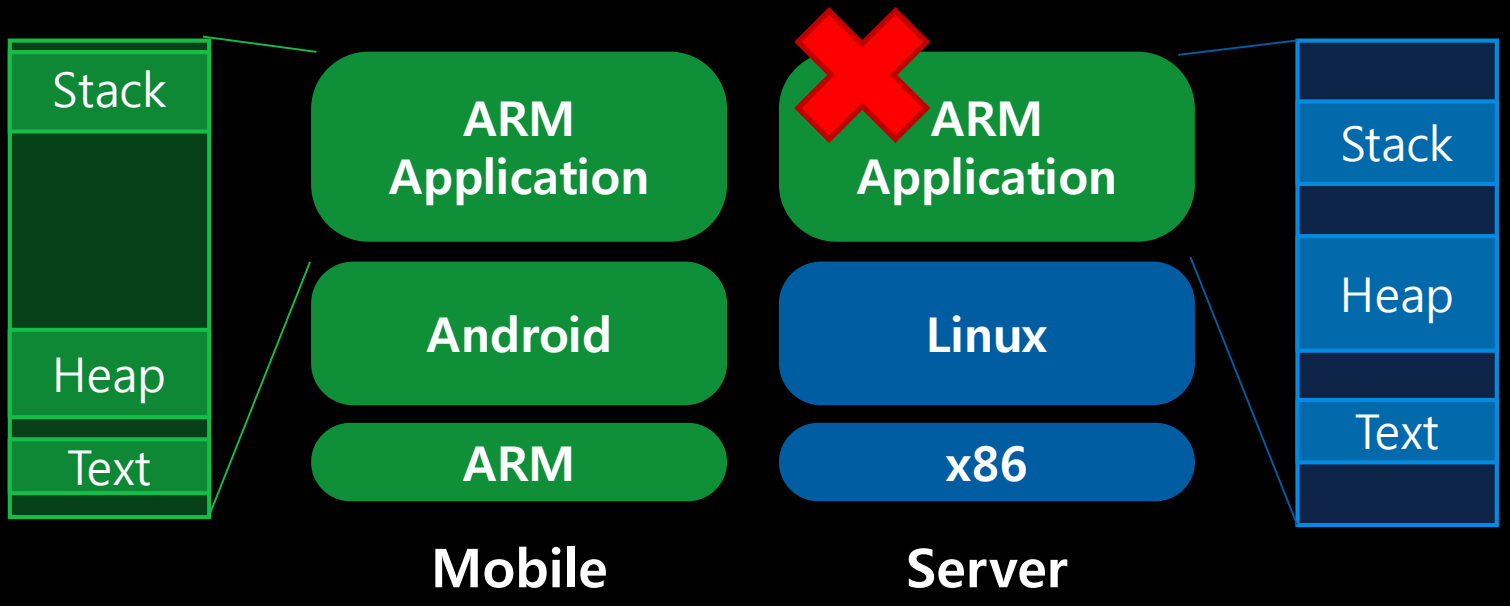


Different Architecture

Distinct Memory

Different Memory Layouts

Challenges in offloading native workloads



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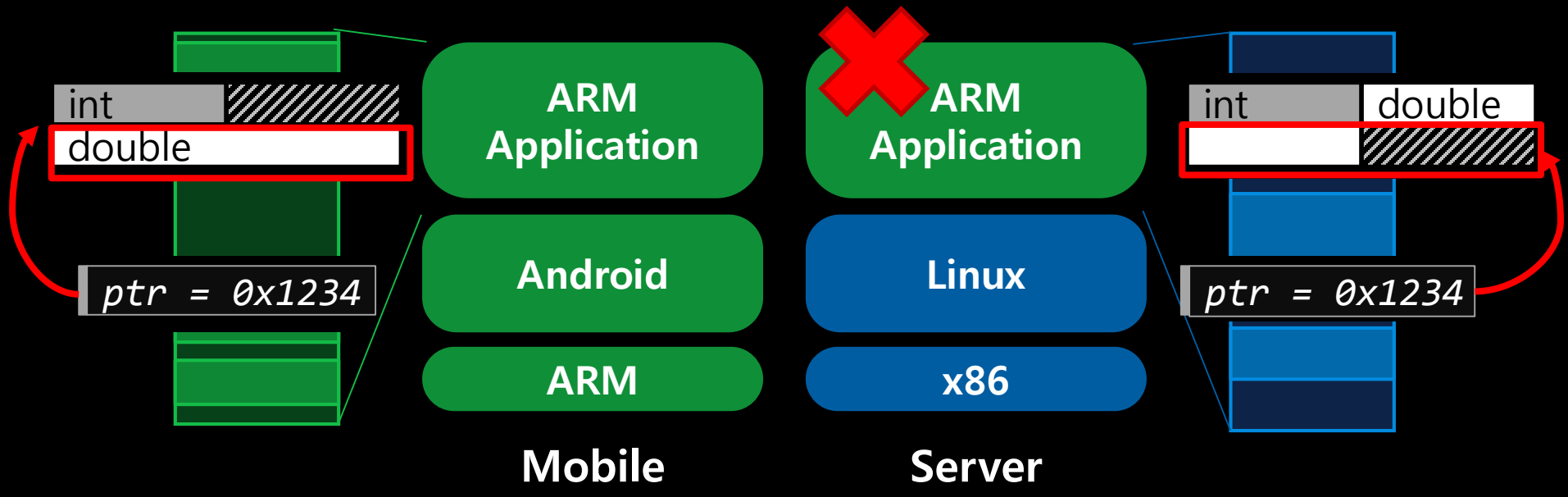
Challenges in offloading native workloads

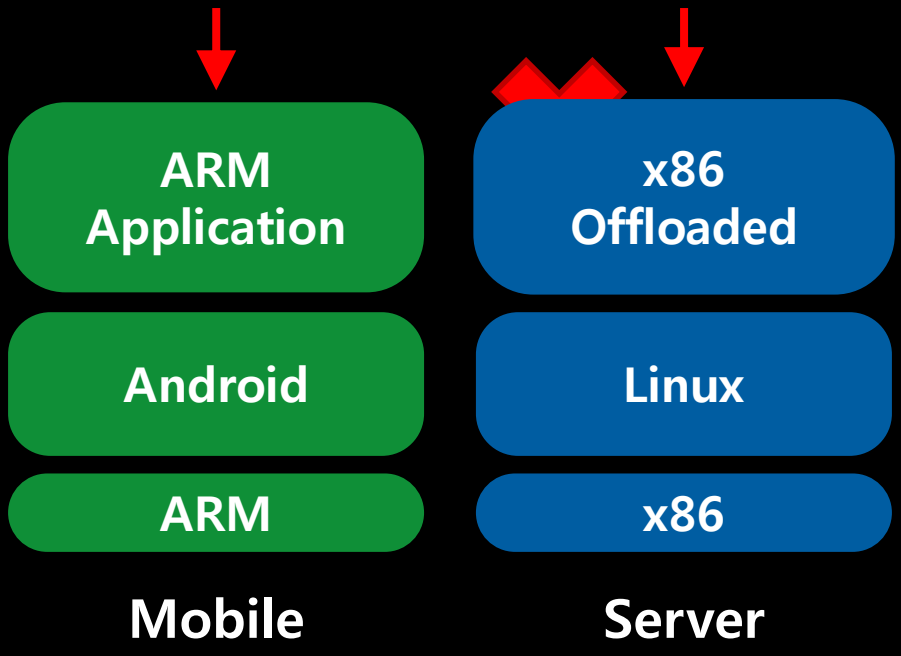


Different Architecture

Distinct Memory

Different Memory Layouts

Our Strategy 1: Compile Both Binaries!

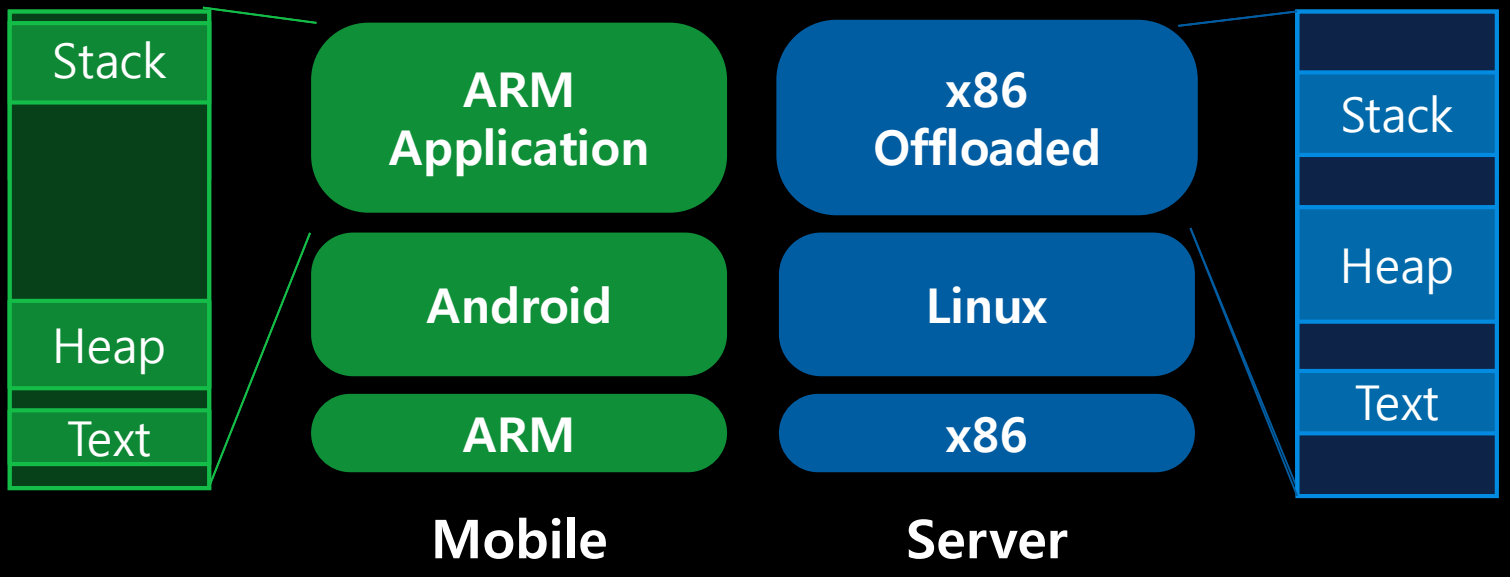


Different Architecture

Distinct Memory

Different Memory Layouts

Our Strategy 2: Unified Virtual Address

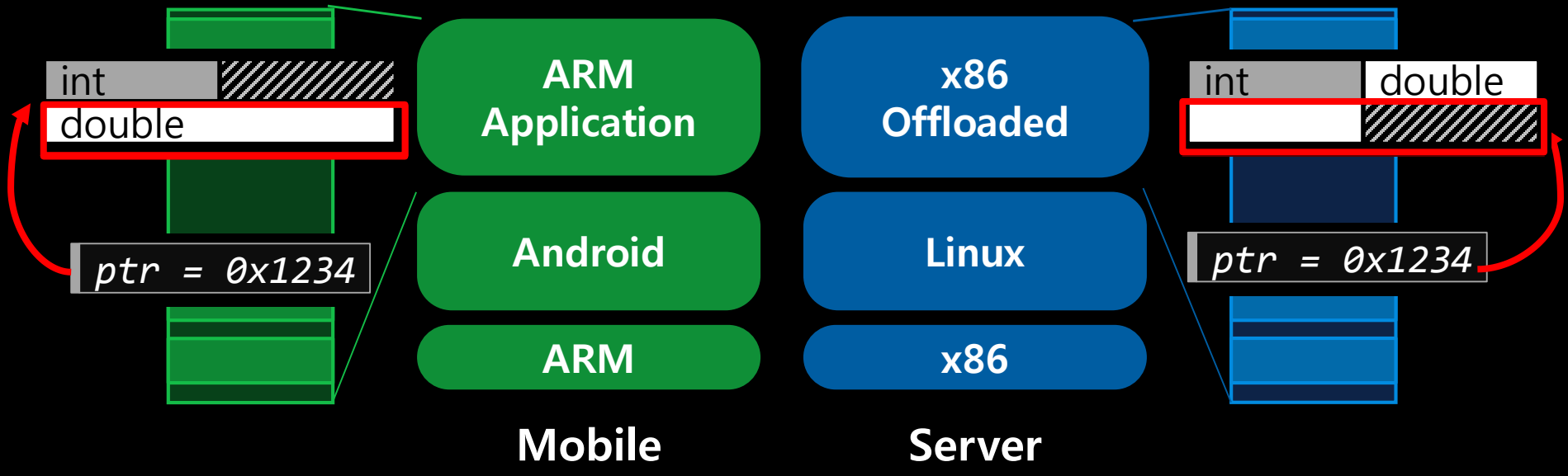


Different Architecture

Distinct Memory

Different Memory Layouts

Our Strategy 3: Unified Memory Layout

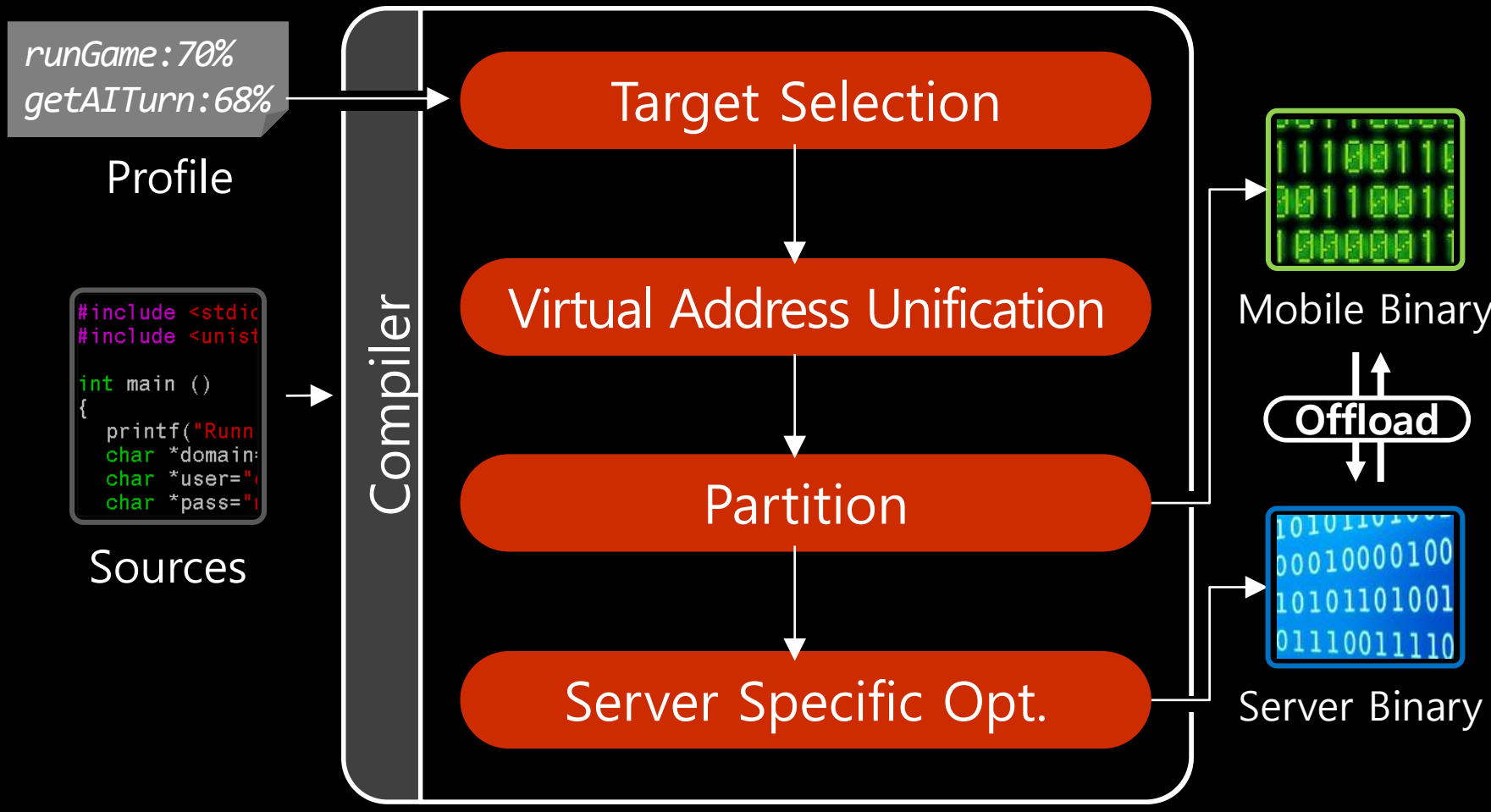


Different Architecture

Distinct Memory

Different Memory Layouts

Native Offloader : Structure Overview



Selecting Profitable Targets

Candidate	Exec. Time	Call Count	Mem. Size
runGame	27 s	1	20 MB
getAITurn	26 s	3	12 MB
~~getPlayerTurn~~	~~1.5 s~~	~~3~~	~~10 MB~~

Estimation

Candidate	Ideal Gain	Comm.	Estimated Gain
runGame	**21.6 s**	**4 s**	**17.6 s**
getAITurn	**20.8 s**	**7.2 s**	**13.6 s**
~~getPlayerTurn~~	~~1.2 s~~	~~6 s~~	~~-4.8 s~~

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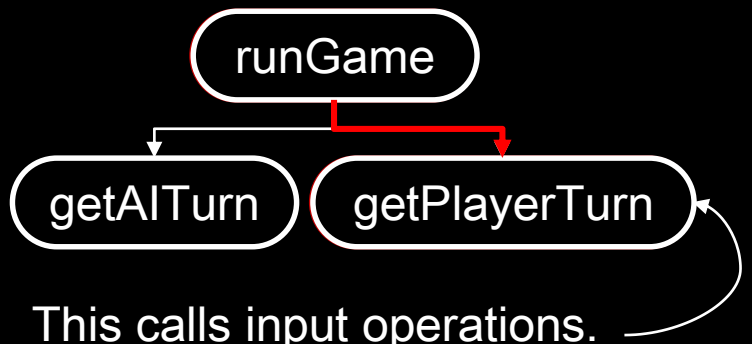

Estimation

Selected →

Candidate	Ideal Gain	Comm.	Estimated Gain
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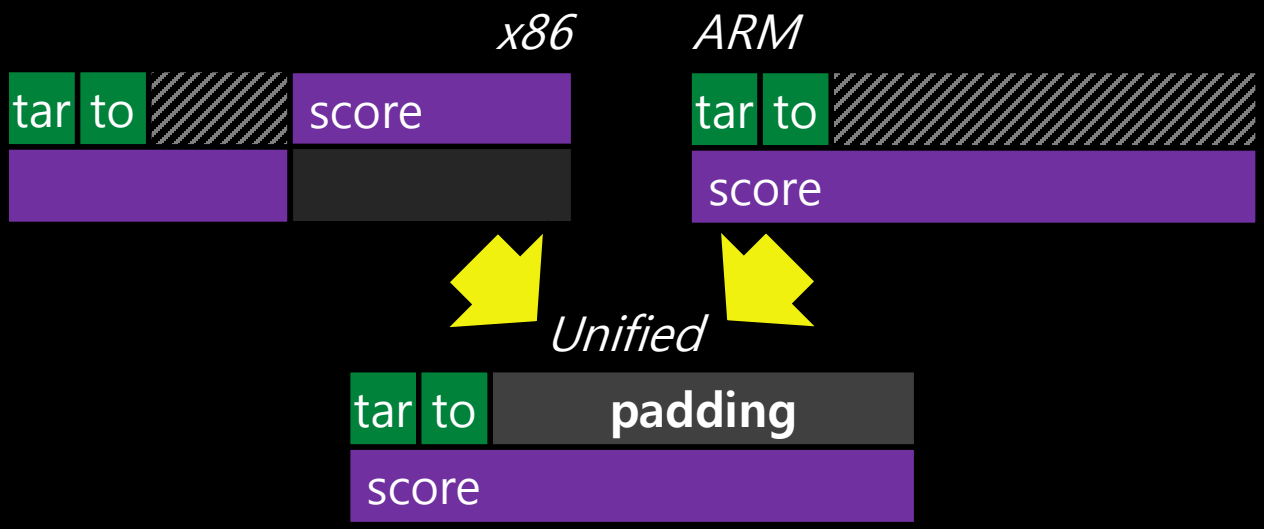
~~getPlayerTurn~~	~~1.2 s~~	~~6 s~~	~~-4.8 s~~

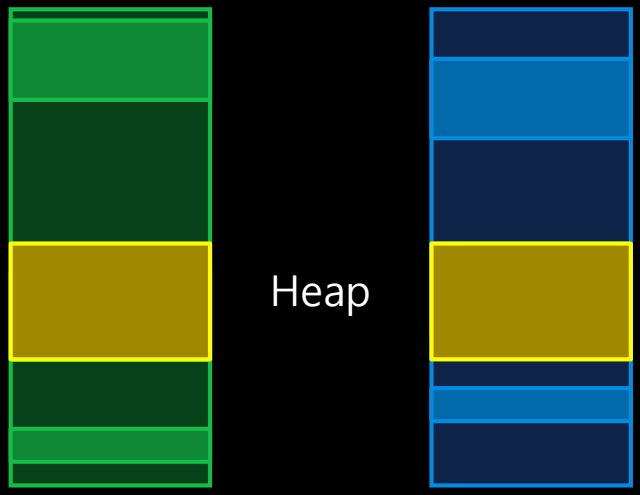
Unifying Structure Layouts

```
typedef struct {
  char tar, to; <pad>; double score;
} Move;
```



Unifying Heap Areas

```
board = u_malloc(sizeof(char) * 32);
u_free(board);
```

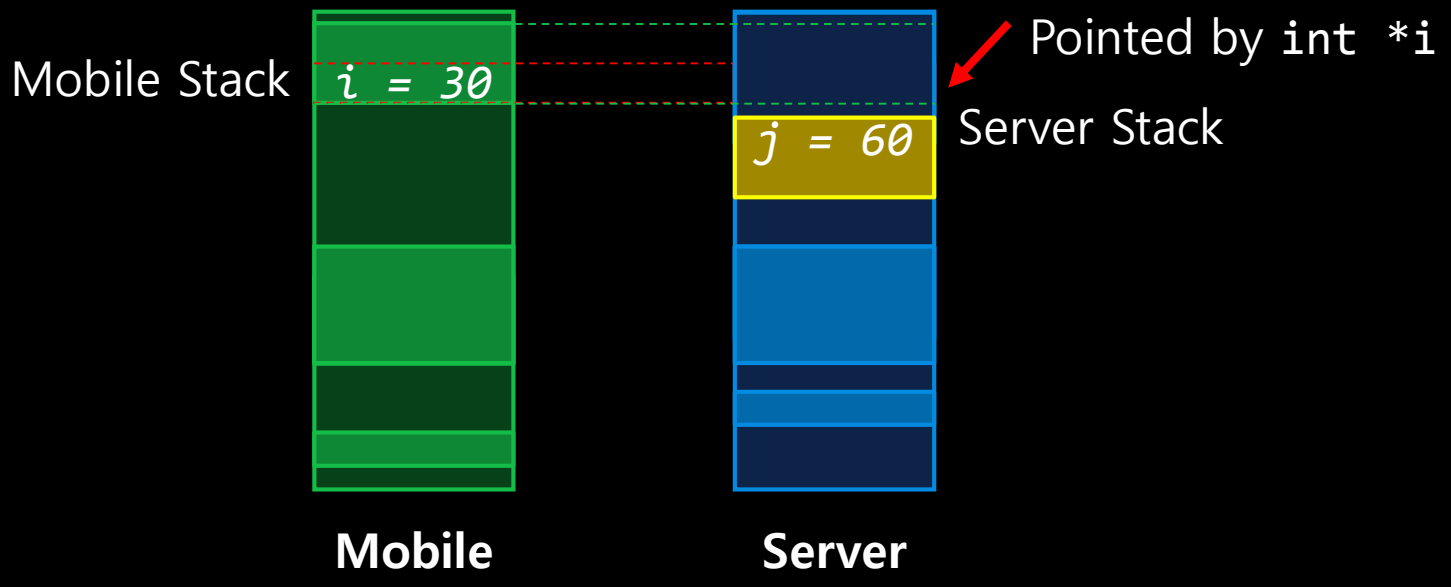


Aligning Two Stack Areas

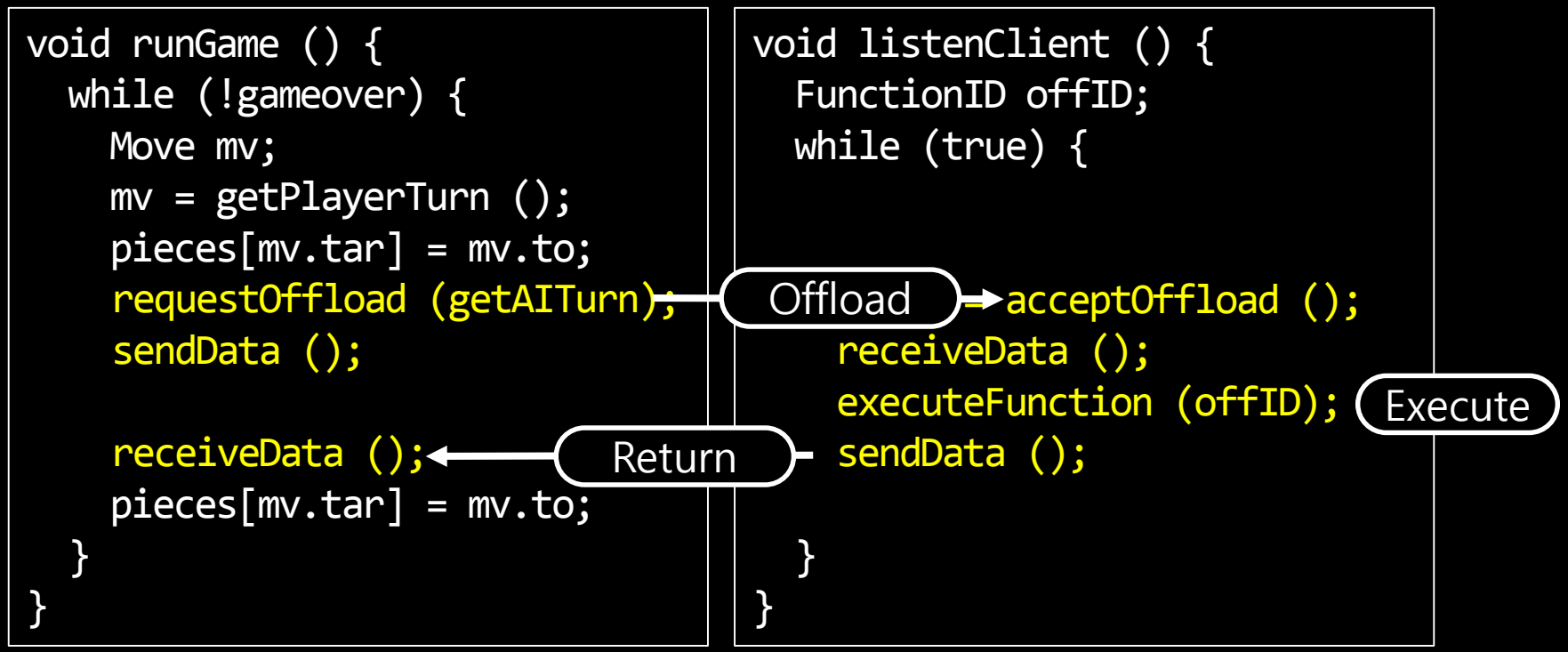
```
int foo () {
  int i = 30;
  bar (&i);
}
```

```
int bar (int *i) {
  int j = 60;
  if (*i!=30) crash;
}
```

*i==60
→ **Crash!**



Partitioning for The Separate Binaries



Server Specific Optimizations

Remote I/O

:: The server's request for I/O operations remotely.

Function Pointer Mapper

:: Maps the mobile's function address to the server's one

Please refer to our paper for more details!

Remaining Challenges for Mobile Apps

Multi-threaded Applications

:: Emerging mobile applications are multi-threaded.

Multi-language Support

:: Mobile apps are written in multiple languages.
ex) Android Apps w/ NDK (Java + C/C++)

So, this work uses SPEC benchmark suites.

Evaluation

Galaxy S5 as the Mobile Device, Dell XPS8700 as the Server

:: Mobile (2.5GHz Quad-core Krait 400)
Server (Intel 3.60GHz Quad-core i7-4790)

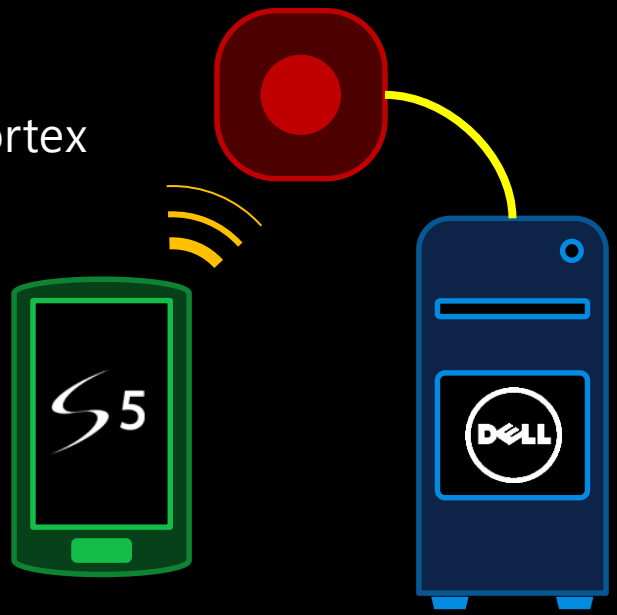
17 SPEC 2000/2006 C Benchmarks

:: LLVM Compile Error: 400.perlbench, 403.gcc
Non-profitable target: 197.parser, 254.gap, 255.vortex

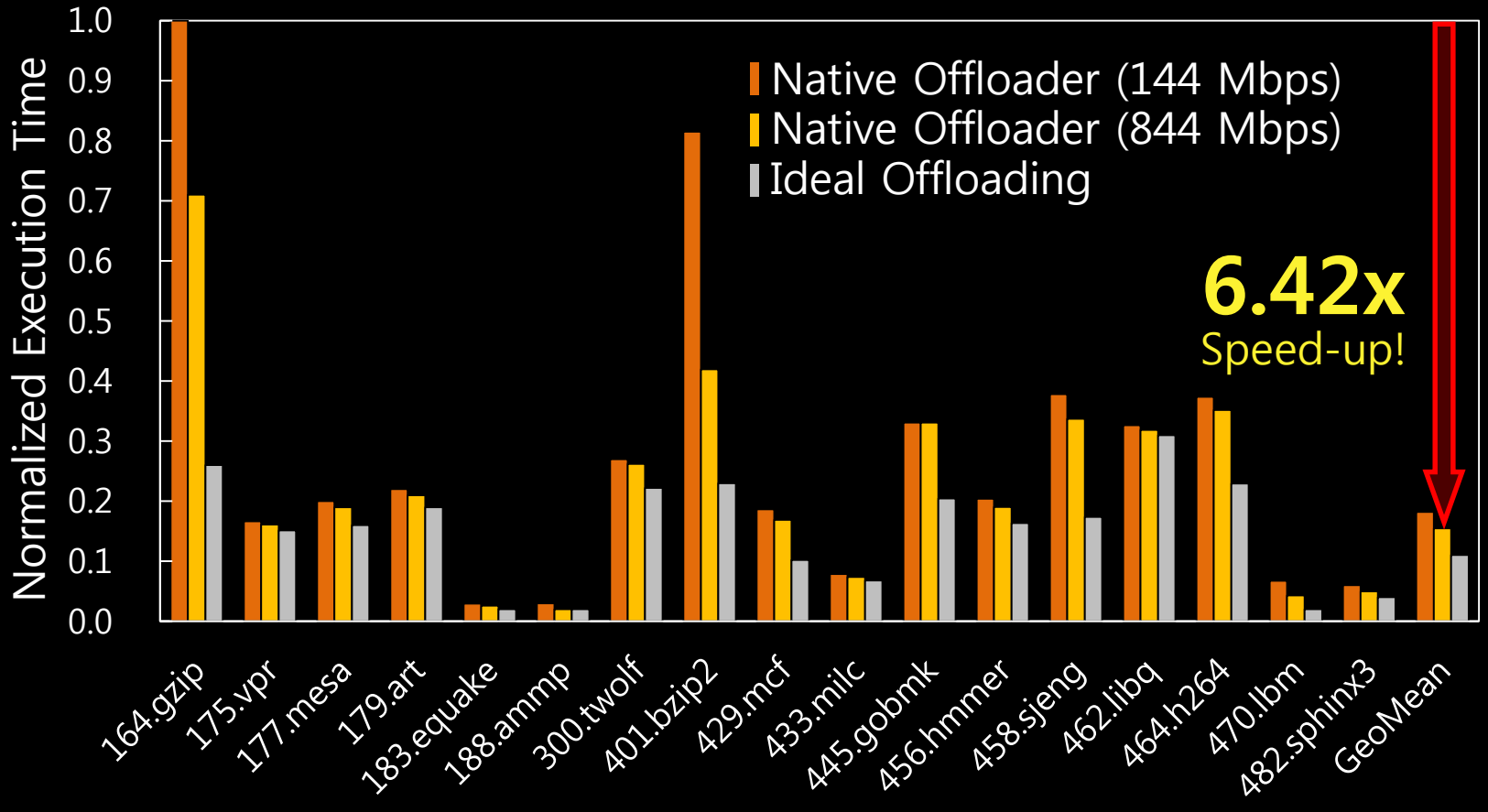
2 Different Network Bandwidths

:: 802.11n (Maximum 144Mbps)
802.11ac (Maximum 844Mbps)

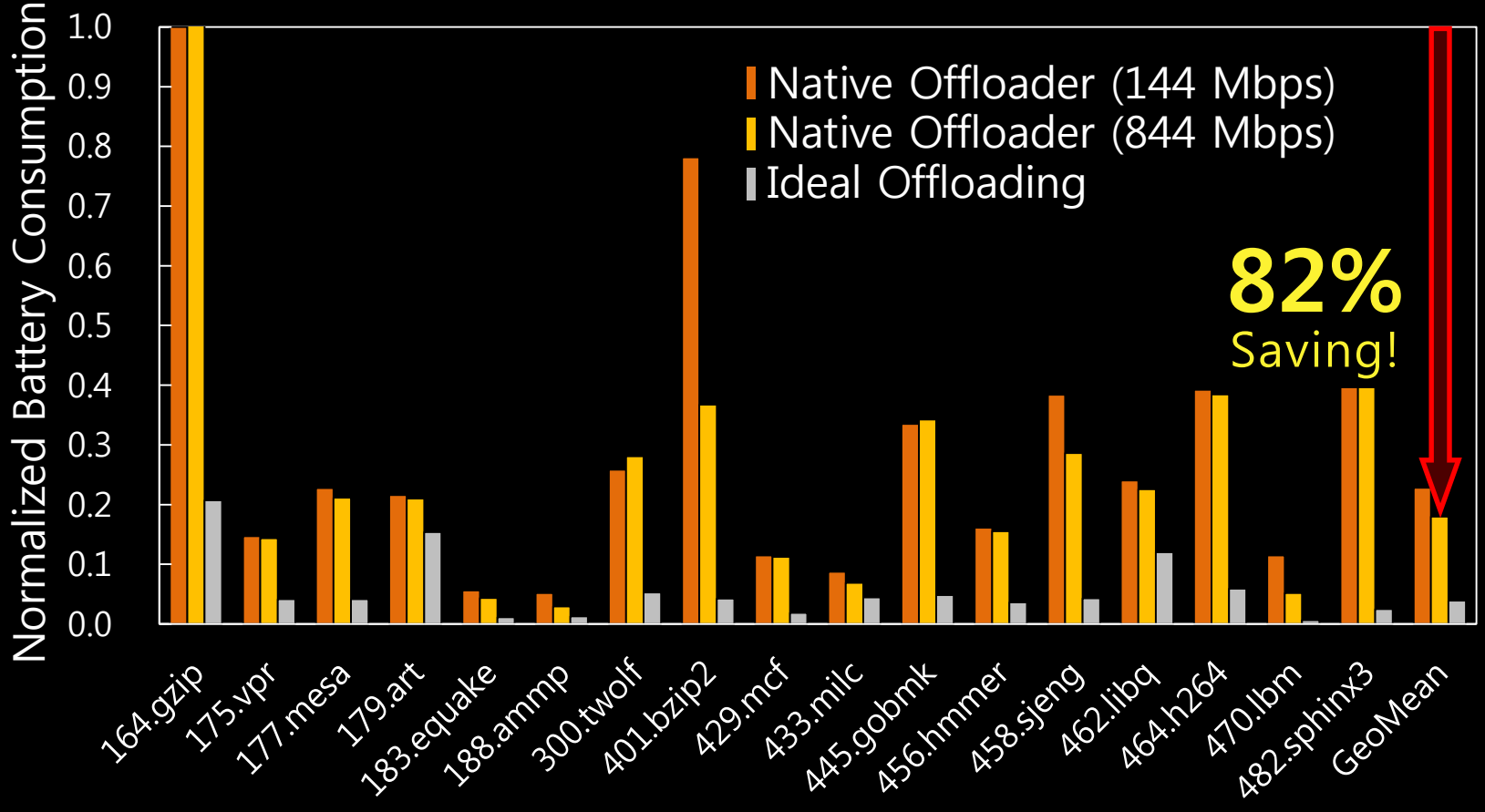
LLVM Compiler Framework



Normalized Execution Time



Normalized Battery Consumption



Conclusion

Native Offloader

:: Compiler/runtime cooperative offloading system for general-purpose native applications

:: To minimize offloading overheads, this work unified virtual address spaces.

Fast & Battery-friendly

:: 6.42x Speed-up / 82% Battery saving for 17 SPEC 2000/2006 C Benchmarks

The paper also includes remote I/O, function pointer mapping, pointer size / endianness translation, runtime system and comm. optimizations.

Image: http://www.worth1000.com/contests/27097/interspecies-teamwork-2

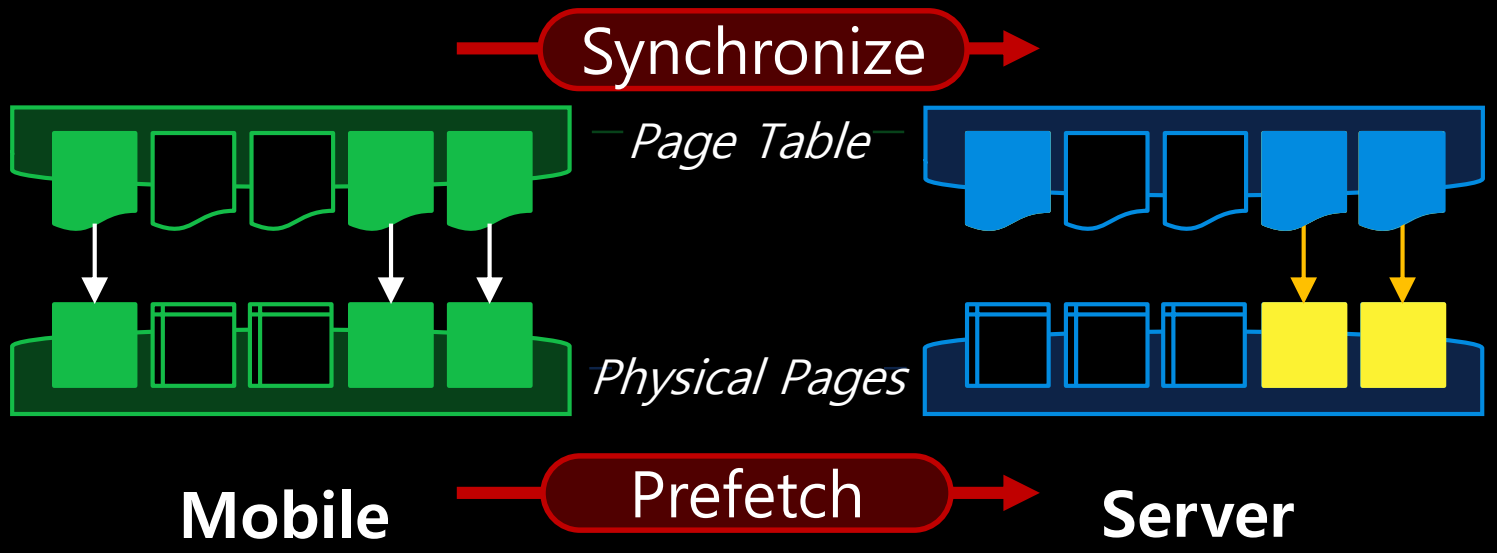
Native Offloader

Architecture-aware Automatic Computation Offload
for Native Applications

Backup Slides

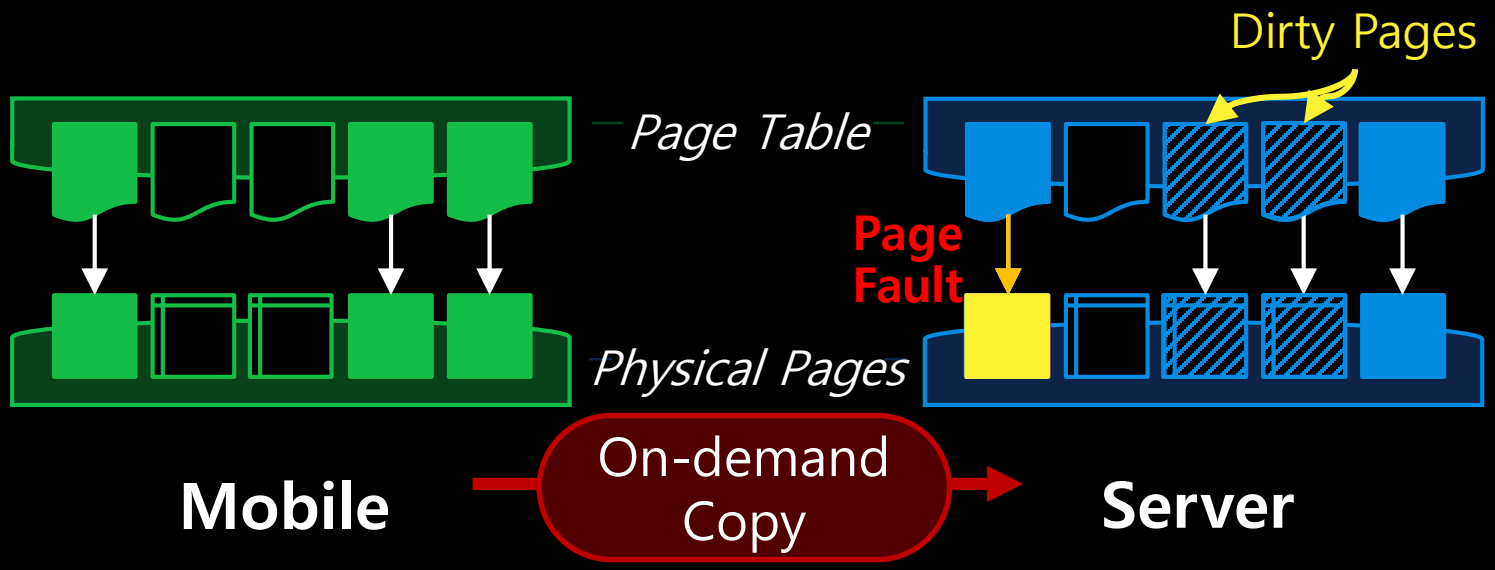
How It Works at Runtime

Stage: *Initialization*



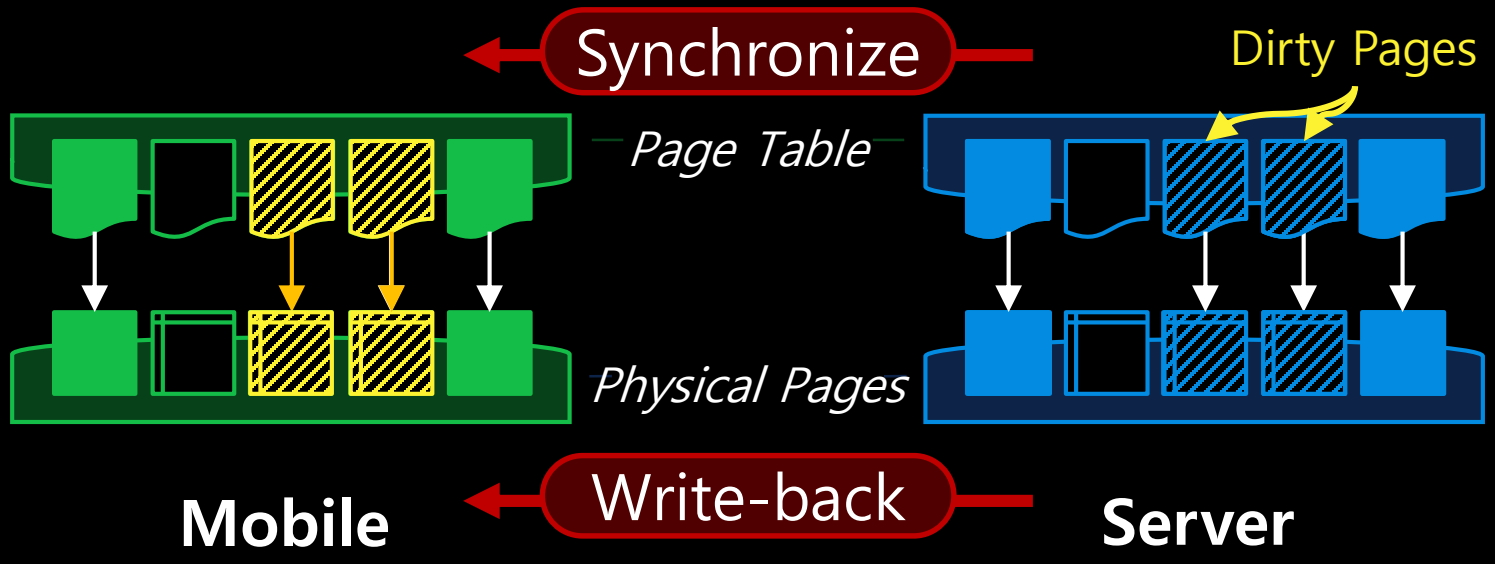
How It Works at Runtime

Stage: *Offloading Execution*

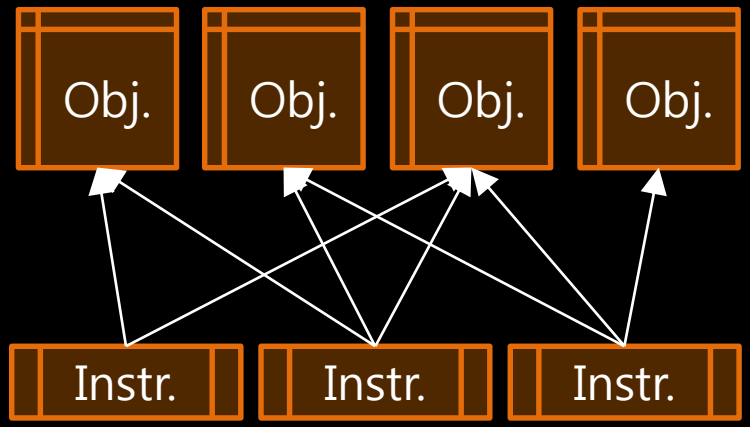


How It Works at Runtime

Stage: *Finalization*

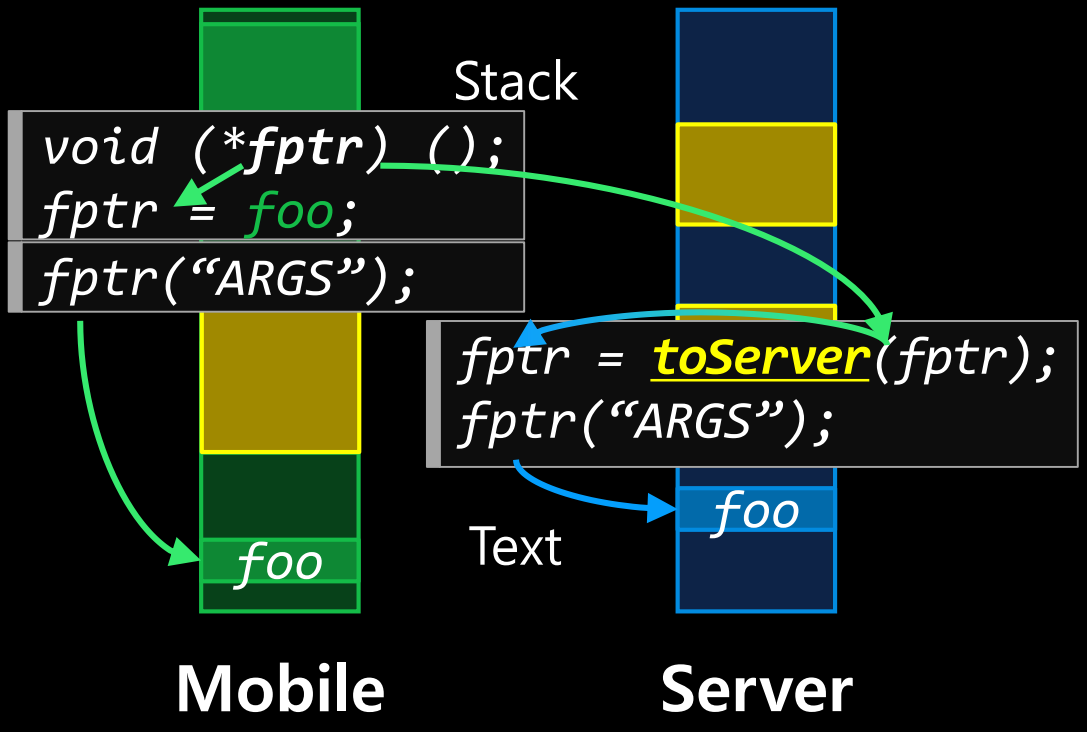


Several offloading systems are already proposed.



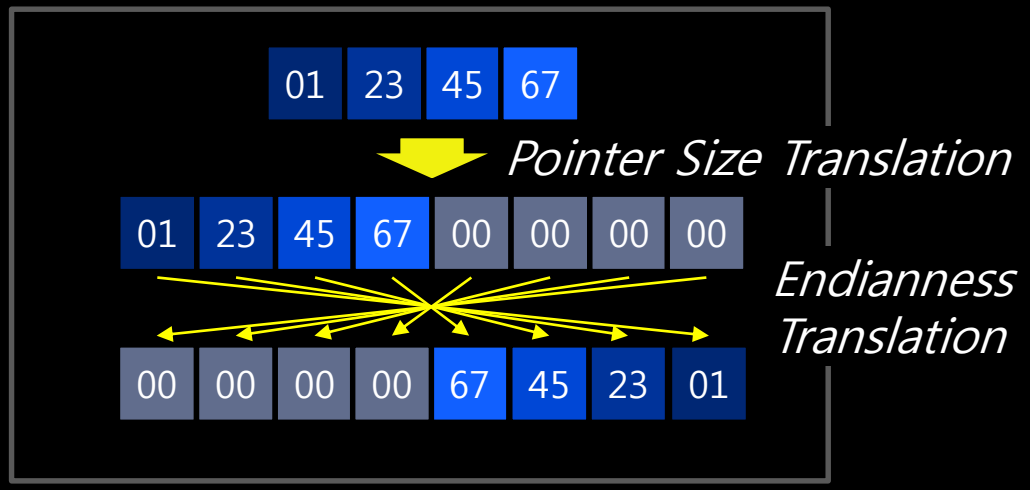
Pointer Analysis-based System
Li et al. (CASES`01), **Wang and Li** (PLDI`04)

Function Pointer Mapping



Unifying the Virtual Address Space

Installing Pointer Size & Endianness Translators



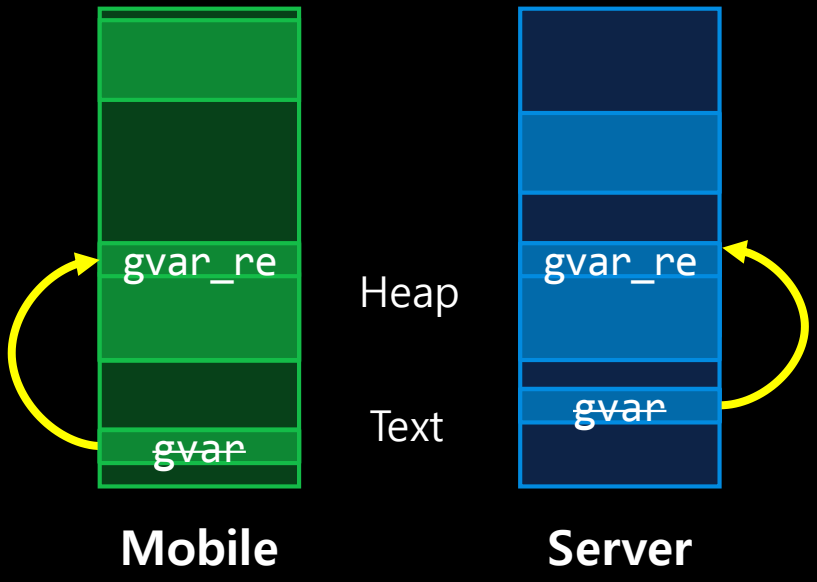

```
int value = *ptr32;
```

```
    ptr64 = zext (ptr32);
int value = toLittle(*ptr64);
```

Reallocating Global Variables

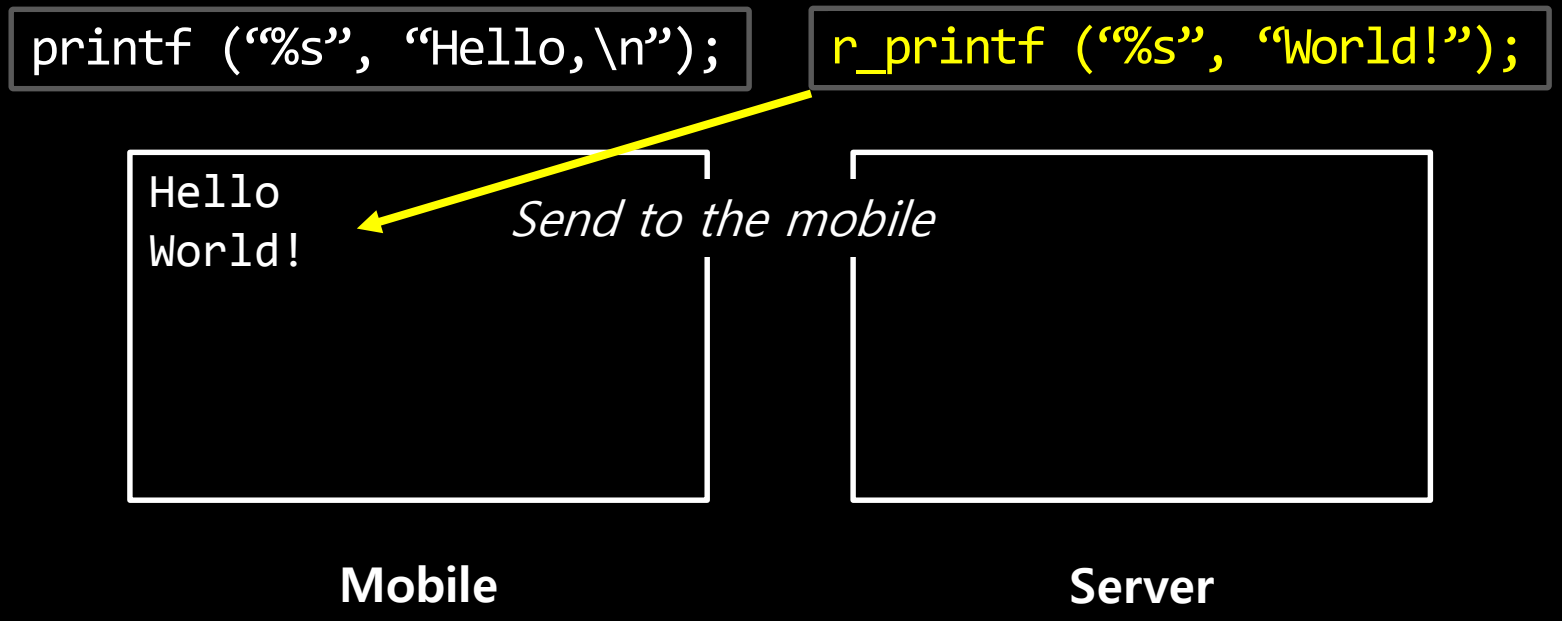
```
int *gvar_re= u_malloc(4);
int *gptr = gvar_re;
```

```
int foo () {
  *gptr = 400;
}
```

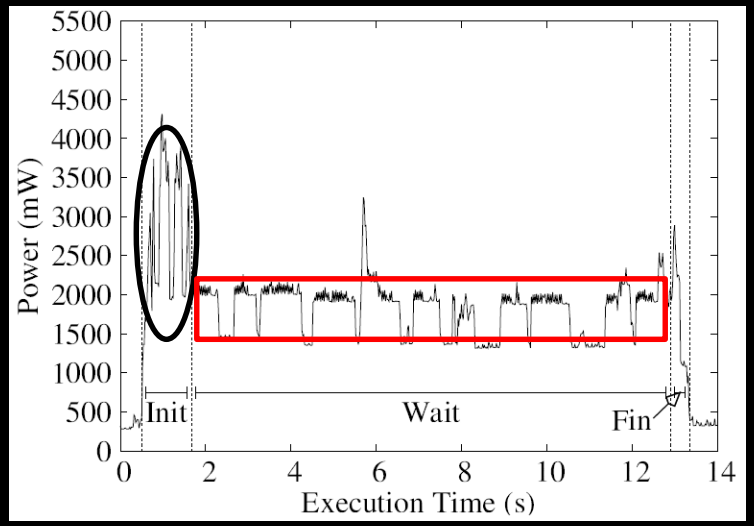


Server Specific Optimizations

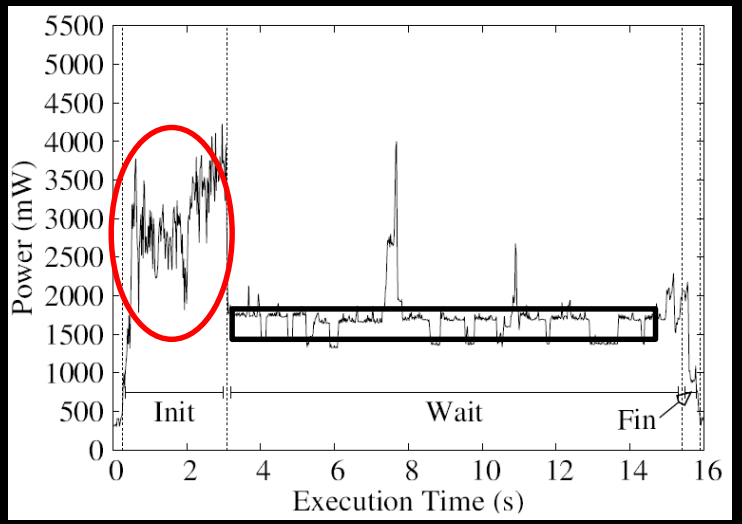
Installing Remote I/O APIs



Runtime Battery Consumption Pattern



445.gobmk (Fast, 802.11ac)



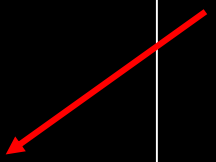
445.gobmk (Slow, 802.11n)

Initial Prefetching Overhead : 802.11ac < 802.11n
\+ Total Remote I/O Overhead : 802.11ac ≫ 802.11n

Total Battery Overhead : 802.11ac > 802.11n

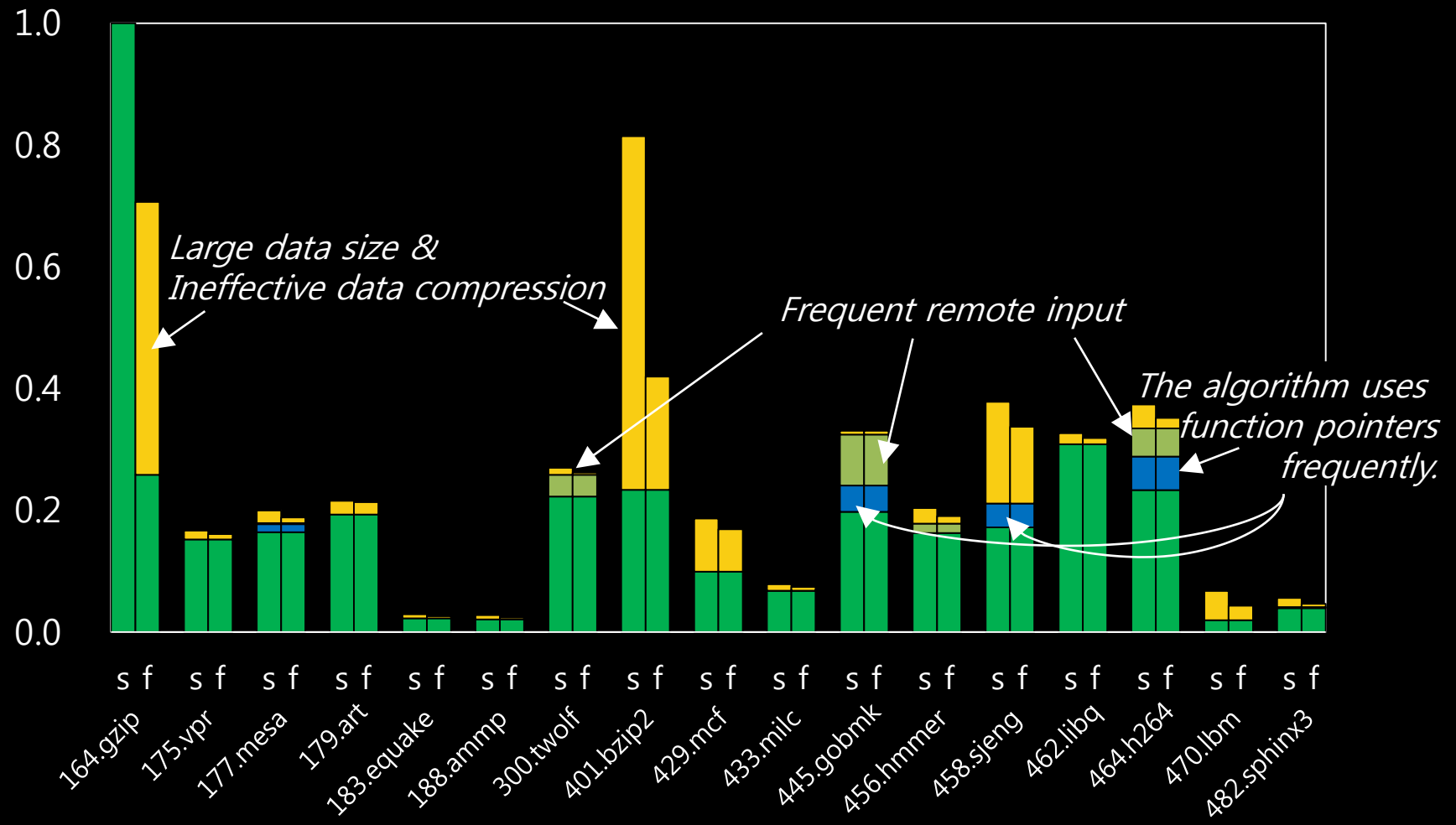
Runtime Estimator

```
void runGame () {
  while (!gameover) {
    Move mv;
    mv = getPlayerTurn ();
    pieces[mv.tar] = mv.to;
    if (profitable (getAITurn)) {
      requestOffload (getAITurn);
      sendData ();
      receiveData ();
    }
    pieces[mv.tar] = mv.to;
  }
}
```



Real-time bandwidth information

Overhead Analysis



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Thank you for your attention!

QUESTIONS & ANSWERS