Tactics-Based Remote Execution for Mobile Computing

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Motivation: mobile interactive applications

- speech recognition, language translation, augmented reality, …
  - Resource-heavy, but need bounded response time
    - » Unfortunately, handhelds are weak!!

Columbia U. MARS project

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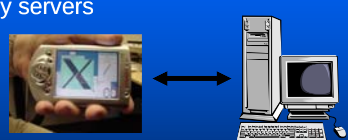
Solution: Remote Execution

- Augment capabilities of handhelds by using nearby servers



- But how can good performance be achieved in mobile environments?
- And easily allow legacy applications to use remote execution?

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Remote Execution Methods

- Static Partitioning
  - Easy to implement
  - Not flexible or effective
- Dynamic Partitioning
  - Most flexible and effective method
  - Extremely hard to implement
- Need a balance between the two

Static Partitioning → Dynamic Partitioning

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Key Insight

For a large number of applications

- Number of useful remote partitions is small
  - Largest so far is 7 partitions
    - » Modular level coarse-grained partitions
- Application developer specifies these partitions (static partitioning)
  - At runtime, pick the optimal partition and locations (dynamic partitioning)

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Solution: Tactics

- Concise description of application's remote execution capabilities
  - Only the useful remote partitions are described
  - Can be captured in a compact declarative form
  - Each tactic performs the required operation
- Tradeoff between dynamic and static partitioning
  - RPC model
  - Assume servers have been discovered and are able to handle any RPC call (no code migration)
  - Coarse-grained remote execution

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Example Tactic

APPLICATION pangloss-lite;

Dictionary → Language modeler
Example based → Language modeler

```
/* RPC Specifications */
RPC server_dict    (IN string line, OUT string dict_out);
RPC server_ebmt  (IN string line, OUT string ebmt_out);
RPC server_lm      (IN string gloss_out, IN string dict_out,
                          IN string ebmt_out, OUT string translation);

/* Tactics (Useful Ways to Combine the RPCs) */
TACTIC dict            = server_dict & server_lm;
TACTIC ebmt           = server_ebmt & server_lm;
TACTIC dict_ebmt    = (server_dict, server_ebmt) & server_lm;
```

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Issues Not Being Tackled

- Usability of handheld devices
  - Focus is on achieving good application performance once the application is running
  - User interaction with the application is out of scope
- Security issues of using handheld servers
  - Minimal authentication of servers is provided
  - No effort to tackle issues like
    - » How do I ensure that the server does the correct thing
    - » How do I prevent the server from reading my data

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Roadmap

- Motivation & Description of Tactics
- Prototype Implementation (Chroma)
  - Components
- Evaluation
- Related Work & Conclusion

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Requirements of Prototype

- Ability to understand tactics descriptions
- Aware of current resource availability
  - Number of remote servers
  - Available bandwidth
  - Battery
- Mechanisms to determine the best tactic for the available resources
  - Need to factor user preferences
    - » Assume that this is provided by external entity (utility functions)

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Components Needed

- Resource Monitors
  - Battery, Bandwidth, CPU, Memory, Available Servers
    - » Use existing service discovery protocols via middleware
- Prediction of Resource Usage
  - History Based Prediction (D. Narayanan's work)
- Solver to match the two
  - Metrics for trading off resources
    - » Latency
    - » Battery Usage (J. Flinn's work)
    - » Fidelity
  - Influence of each metric in process is user-specific

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What is fidelity?

- Fidelity ≈ runtime tunable quality
  - Extent to which it matches a *reference* result
  - Used to compare quality of different executions of application
  - System changes fidelity by setting knobs in the application at runtime
- Application-specific metric(s) / knob(s)
  - resolution for augmented reality rendering
  - vocabulary size for speech recognition
  - JPEG compression level for web images
  - …

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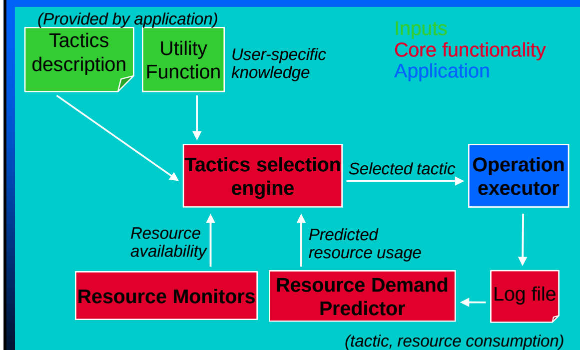
Chroma



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Evaluation objective

- To show that Chroma has comparable performance to an oracle
  - Oracle selects best tactic for current environment
  - Oracle's selection is determined offline while Chroma selects online
- Is the overhead of Chroma acceptable?
- Use of extra servers
  - What additional performance benefits are possible?

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Applications Used

- Three real research applications
  - Useful for mobile users

1. Pangloss-Lite is a natural language translator **[Federking @ CMU]** (7 tactics)
   » Valuable for travelers in foreign countries
2. Janus is a speech recognizer **[Waibel @ CMU]** (2 tactics)
   » Key component of speech interfaces
3. Face detects faces in images **[Schneiderman @ CMU]** (1 tactic)
   » Representative of surveillance applications

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Experimental Setup

- Thinkpad 560X Client (200 Mhz Pentium)
  - Representative of fastest handhelds
- HP Omnibook 6000 Servers (1 Ghz Pentium 3)
- 100 Mb/s Ethernet
- Testing methodology
  - Different inputs representing an operation
  - Each result average of 20 runs
  - State of system reset before each run

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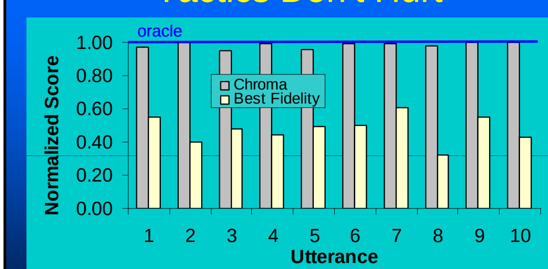
Tactics Don't Hurt



Application: Janus, Metric = $\frac{fidelity}{latency}$

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Tactics Don't Hurt

Utterance	Oracle		Chroma		Score
	Latency (s)	Fidelity	Latency (s)	Fidelity	
1	0.71	0.50	0.73	0.50	0.97
2	1.00	0.50	1.00	0.50	1.00
3	0.76	0.50	0.80	0.50	0.95
4	0.78	0.50	0.79	0.50	0.99
5	0.99	0.50	1.03	0.50	0.96
6	0.95	0.50	0.96	0.50	0.99
7	0.70	0.50	0.71	0.50	0.99
8	1.20	0.50	1.22	0.50	0.98
9	0.77	0.50	0.77	0.50	1.00
10	0.99	0.50	0.99	0.50	1.00

Application: Janus, Metric = $\frac{fidelity}{latency}$

Location : Remote in all case

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Overhead Concerns

- Does the solver take too long?
  - Can it handle a large number of tactics?
  - What happens when the number of servers increases?
- Complete system overhead
  - How long does the system need to make decisions on a slow client?
    - » Includes solver overhead + overhead of resource measurement & prediction

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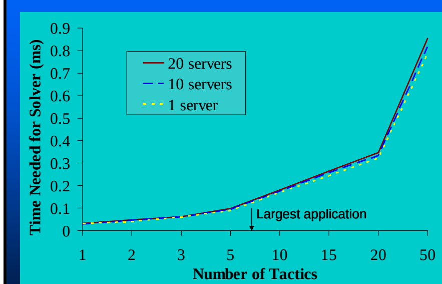
Overhead of Solver



- Synthetic results
- Slow client
- Max overhead < 0.9 ms
- Okay for interactive apps

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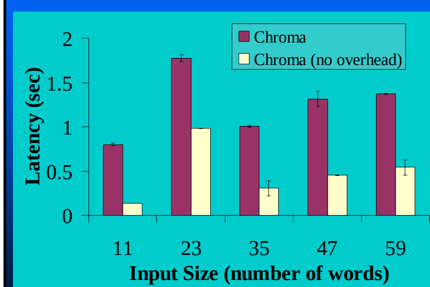
Overhead of Entire System



- Pangloss - Lite
- Slow client
- Max overhead < 1 s
- Measurers can be slow
  - Caching helps

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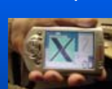
Adjusting to Environment

- Availability of compute servers varies wildly
  - Mobility ⇒ Cannot expect just one situation

Resource Poor



Resource Rich
(Smart Rooms etc.)

- Tactics allow us to automatically use extra resources in environment
  - Without modifying the application

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Why is this Useful?

- Shields application from uncertainty in environment
  - Load on servers, wireless bandwidth
  - Execute same tactic on multiple servers
    - » Take fastest result
- Opportunistic execution
  - To meet latency constraints
  - Execute multiple tactics on multiple servers
    - » Return highest fidelity result that satisfies latency constraints

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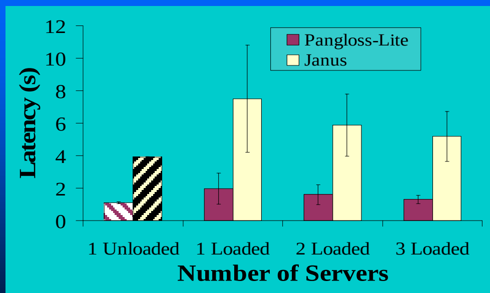
Tactics: Using Extra Servers



Still able to get performance improvements with loaded servers!!

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Meeting Latency Constraints

	Fidelity	Latency		Metric
		Average (s)	Standard Deviation (s)	
Running to Completion	1.0	1.96	0.15	0.51
Taking Best Result after 1s	0.75	1.00	0.01	0.75

Application = Pangloss-Lite

Thinkpad 560X (200 Mhz Pentium)

$$\text{Metric} = \frac{\textit{fidelity}}{\textit{latency}}$$

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Related Work

- Application-aware remote execution systems
  - Abacus (Amiri), Coign (Hunt), Condor (Basney)
    - » Not meant for mobile environments
  - Odyssey (Noble, Narayanan, Flinn), Spectra (Flinn),
    - » Good performance in mobile environments
    - » Hard to add new applications
- Other remote execution systems
  - Puppeteer (De Lara), Emerald (Jul), Sprite (Ousterhout)

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Future Work

- Validate generality of tactics
  - Via multiple application case studies
  - Computationally intensive interactive apps
- Integration of service discovery mechanisms
- Use of extra servers
  - Distributed resource scheduling mechanisms

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Conclusions

- Tactics are a valuable method of describing remote execution
  - Tradeoff between static partitioning and full dynamic code migration
  - Allows development of powerful remote execution systems
  - Amenable to software engineering methods to ease application development

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