Tactics-Based Remote Execution

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Motivation: mobile interactive applications

- speech recognition, language translation, augmented reality, …
  – Resource-heavy, but need bounded response time

Columbia U. MARS project

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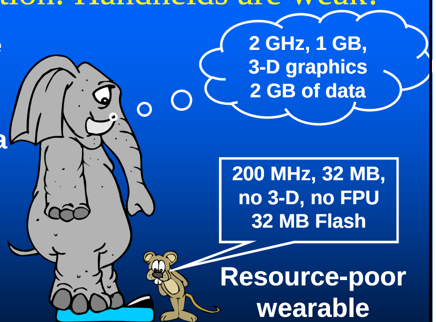
Motivation: Handhelds are weak!

- Resource intensive App
- Huge Data Sets



Resource-poor wearable

Poor performance!

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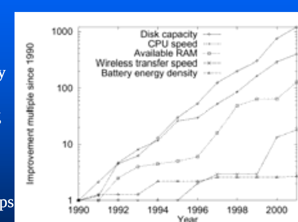
But what about Moore’s Law

- Exponential resource increase
  – CPU, Memory, Disk
- Not quite true for handhelds
  – Battery capacity has increased only linearly
  – Wireless bandwidth not increasing as fast as wired bandwidth
    » 1 Gb/s versus 54 Mb/s
    » Very uncertain bandwidth
  – Applications developed for desktops
  – Design/Space constraints
    » Memory, CPU sacrificed to obtain decent battery life in given form factor



Courtesy Thad Sterner, Gatech

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Implications

- Handhelds will have problems running computationally intensive applications
  – Language translation, speech recognition, augmented reality etc.
- They can choose to
  – Not run these types of applications
  – Run these applications with terrible performance
  – Run specially created “lite” versions of these applications
    » Takes a long time to develop
    » Requires a separate development group
    » May not satisfy the user

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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?
- First work to address both concerns

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Roadmap

- **Thesis Statement**
  - **Importance, Difficulty, Domain and Validation**
- What are Tactics?
- Prototype Implementation (Chroma)
  - Components
  - Evaluation
- Tools for Supporting Tactics
  - Evaluation
- Timeline, Related Work & Conclusion

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Thesis Statement

- Full range of meaningful partitions of an application can be described in a compact external description
  - **Remote execution tactics**
  - Partitions ➡ remote execution possibilities of an app
- Demonstrate the two-fold benefits of tactics
  1. Enables powerful remote execution system
     - » Provides good application performance at runtime
     - » Low overhead
     - » Automatic
  2. Amenable to sound software engineering principles
     - » Decrease the time needed to develop mobile applications for new hardware platforms
     - » “Easy” to use

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Why is this Work Important?

- Solution to a fundamental tension in developing mobile apps
  - Mobile environments are inherently uncertain and dynamic
    - » Bandwidth, availability of remote servers, battery life
  - Tackling this uncertainty requires automatic partitioning decisions
    - » Otherwise, granularity of adaptation is too slow
  - But, optimal partitions are frequently application and runtime specific
    - » Automatic partitions may not perform well
  - Tactics provide the required balance
    - » Uses application/runtime specific information
    - » Yet allows dynamic runtime adaptation to cope with uncertainty

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Why is this Work Hard?

- Formulating explicitly the notion of tactics
  - What are their semantics?
  - How do you specify them?
  - What application types does it work for?
  - What are the strengths and limitations of tactics?
- Need to prove that tactics can be successfully used by an adaptive runtime system
  - Runtime has to deal with the uncertain mobile environments
    - » Yet make dynamic partitioning choices that are good
- Making existing applications use tactics must be easy
  - For system to be usable in practice
  - Achilles heel of many other adaptive systems

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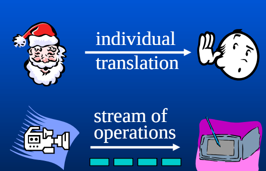
Model of Applications

- Computationally intensive interactive applications
  - have operations that do useful work
    - » An “operation” is an application specific notion of work
      - Translate a sentence
- 2 main flavours
  - Discrete
    - » Language Translation
    - » Speech Recognition
  - Continuous
    - » Video Streaming



- Differ in 2 key aspects
  - Rate of input arrival
  - Cost of setting up state required to perform the operation

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Model of Applications (Cont)

- Application is classified according to
  - It’s behaviour
    - » Language Translation (Discrete)
      - 1 sentence every second
      - State cost is usually minimal
        - Each input is independent of other inputs
        - State cost is high when the model or language changes
    - » Video Streaming (Continuous)
      - ~30 frames per second
        - Making a decision for each frame may take too long
      - Decoding frame x may be dependent on decoding frame x-1
  - Capabilities of current system
    - » Slower system -> fewer discrete applications

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Issues Not Being Tackled

- Usability of handheld devices
  - Thesis focus is on achieving good application performance once the application is running
  - How the user interacts with the application is out of scope
- Security issues of using handheld servers
  - Minimal authentication of servers may be 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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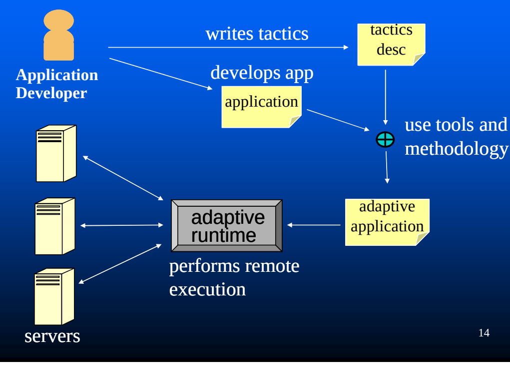
From 10,000 Feet



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Proposed Validation

The following need to be validated

- Expressive power of tactics is adequate for the class of applications targeted
- Proof of concept of
  - Prototype tactics-based remote execution system
    - Can provide good application performance
  - Tools to assist application development
    - Can shorten application development time

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Validation of Tactics

- Goal
  - Generality of tactics
    - Tactics semantics are able to support the class of applications targeted
- Validation via multiple application case studies
  - 4 discrete applications have currently been validated
  - At least 4 additional different applications needed for validation
    - To ensure that the application domain space is well mapped
    - Applications that I plan to add
      - Map application
      - Video streaming application

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Validation of Remote Execution Prototype

- Goal
  - To show that tactics can be used to build high performance adaptive systems
    - Performance of prototype with various applications and environments is excellent
- Effectiveness in different resource environments needs to be measured
  - Ability of system to deal with resource uncertainty
    - Changes in wireless bandwidth
    - Addition or removal of remote servers
  - Initial testing with 3 applications has been promising

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Validation of Tools

- Goal
  - Tactics are amenable to the use of tools and software engineering methods to ease application development time
- Validation of tools and methodology for easing application development time
  - Initial experiments with 4 applications have been positive
    - Method has to be applied to many more applications
  - When do the tools and methods help? When do they fail?
    - Compare time to add new applications with and without tools and methodology
      - By both experienced and inexperienced users

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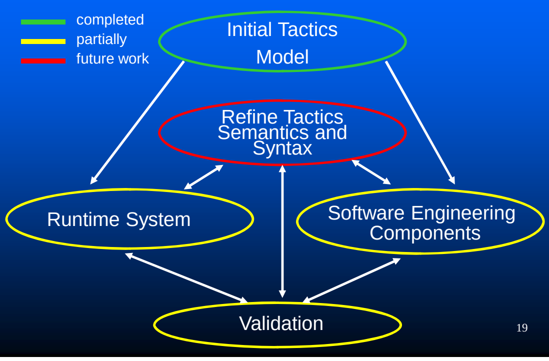
Current Status



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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

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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
  - Allows use of stub generators to ease programming burden
- Tradeoff between dynamic and static partitioning
  - RPC model, no code migration
  - Coarse-grained remote execution

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Tactic Semantics

- Tactics support the following semantics
  - Specify RPCs that make up the tactics
  - Allow RPCs to be executed in sequential order
  - Allow RPCs to be executed in parallel
    - » Useful for applications with multiple optional components
      - E.g., language translation using different quality engines
  - Combination of sequential and parallel specifications
  - Specific server group specifications for any RPC
    - » Useful for security or licensing reasons

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Example Tactic

APPLICATION pangloss-lite;

/* 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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Initial Validation

- Four real research applications
  - Useful for mobile users

1. Pangloss-Lite is a natural language translator **[Federking @ CMU]**
   - » Valuable for travelers in foreign countries
2. Janus is a speech recognizer **[Waibel @ CMU]**
   - » Key component of speech interfaces
3. Face recognizes faces in images **[Schneiderman @ CMU]**
   - » Representative of data mining applications
4. GLVU renders 3D objects **[Brooks @ UNC]**
   - » Augmented reality

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To Be Done

- Validation of tactics
  - Currently, 4 applications have been looked at
  - More applications need to be described using tactics to map application domain
    - » Good mix of continuous and discrete applications
- Refine syntax and semantics based on case studies

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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

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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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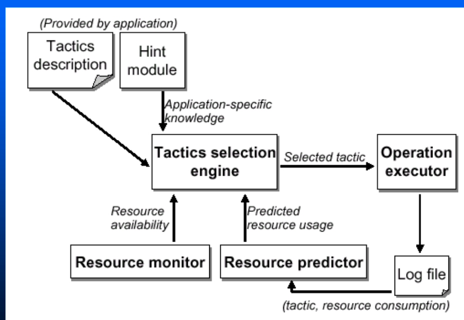
Chroma



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Validation

- Do tactics allow good system performance?
  - Performance of prototype for various applications will answer question
- Performance of 3 initial applications measured
  - Pangloss-Lite (Natural language translator)
  - Janus (Speech recognizer)
  - Face (Data mining)
- Performance is comparable to hand-modified application
  - Constant overhead added by runtime
  - Overhead is low and reasonable

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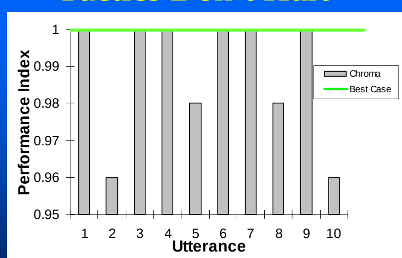
Tactics Don't Hurt



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

Thinkpad 560X (200 Mhz Pentium)

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What's Next?

- Refine initial prototype
  - Support for continuous applications
  - Integration of service discovery middleware
  - Support for automatically using additional servers
    - » Support for both famine and feast environments
- Integration with layer monitoring user preferences
  - To obtain hint modules
  - Prism in the Aura context
- Validation with numerous other applications
  - At least 2 continuous applications

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Problem: Making existing applications adaptive

- Modification of existing applications to support mobility is necessary
  - Not practical to rewrite existing apps from scratch
- However, these modifications are hard
  - Require expert knowledge of app
  - Need knowledge of runtime system
  - Modifications need to be updated every time either app or runtime changes

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Our Approach

- Key insight
  - Adaptation information can be described in an external form
    - » Adaptation => remote execution + changing runtime parameters
    - » Application and runtime independent
    - » Cleanly separates adaptive behaviour from application code
    - » Leads naturally to code reuse etc.
- Benefits of our approach
  - Much easier to preserve adaptation across software changes
    - » Separation and level of indirection allow tools like stub generators
  - Easier to change policies for adaptation
  - Allows development of a specialized software engineering methodology to ease development time

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What Does It Work For?

- Not a magic bullet
- Works for the following application types
  - Well defined procedures for remote execution
    - » Amenable to the RPC model
  - Well defined processing loop that performs the main work of the application
    - » Rendering loop in graphics apps
    - » Receive a sentence and translate it
  - Violation of either principle may require the application to be restructured
    - » Costly process

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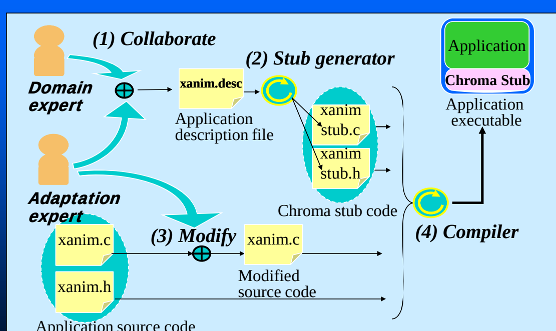
Adaptation in 4 easy steps



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API Calls (Current)

Basic
- Register :- Register app with Chroma
- Cleanup :- Destroys all data structures

For Resource Logging
- Start_operation :- Tells Chroma to start logging resource usage
- Stop_operation :- Tells Chroma when to stop

Core Functionality
- Find_fidelity :- Asks Chroma to return appropriate fidelity vals
- Do_tactics :- Tells Chroma to perform any remote executions

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Case Study: Pangloss-Lite

```
Application panlite;

IN integer nwords FROM 0 TO infinity DEFAULT 1;

RPC server_gbt    (IN string line, OUT string gbt_out);
RPC server_ebmt  (IN string line, OUT string ebmt_out);
RPC server_lm     (IN string gbt_out, IN string ebmt_out,
                          OUT string translation);

TACTIC gbt           = server_gbt & server_lm;
TACTIC ebmt          = server_ebmt & server_lm;
TACTIC gbt_ebmt      = (server_gbt, server_ebmt) & server_lm;
```

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Case Study: Pangloss-Lite

```
params = panlite_translate_initialize_params ();
while (do_translation) {
    /* read input into "line" and do other processing */
    panlite_translate_set_nwords (params, value);
    panlite_translate_find_fidelity (params);
    panlite_translate_do_tactics (params, line, translation);
    /* display translation and do other processing */
}
panlite_translate_cleanup_params (params);
```

Figure 5: Modifications to Pangloss-Lite

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“Comprehensive” Validation

- Method is somewhat language independent
  - Three test applications were all different languages
    - » C, C++ and Ada
- Minimal hand modification of actual code
  - ~17 lines for Pangloss-Lite
  - ~50 lines for Face
  - ~25 lines for Janus

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What’s Missing?

- Mechanisms to make server development easier
- Proper validation
  - Time to add applications to system using the tools and methods measured for
    - » Experienced user
    - » Novice user
  - Using a large number of applications (at least 3 more)
    - » Mix of both discrete and continuous

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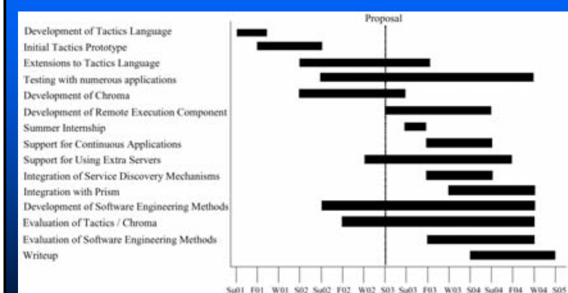
Timeline



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Related Work

Remote Execution Systems

- Application-Aware
  - Interested in obtaining good performance by modifying applications
  - Not meant for mobile environments
    - » Abacus (Amiri), Coign (Hunt), Condor (Basney),
  - Early work on adaptation for mobile environments
  - Required huge amounts of work to add applications to runtime
    - » Odyssey (Noble, Narayanan, Flinn), Spectra (Flinn),
- Application-independent
  - Concentrates on adapting applications with no application modifications
  - Does not perform as well as application-aware adaptation
    - » Puppeteer (De Lara)

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Related Work (Cont)

- Object Migration
  - Treats components as objects
  - Not meant for mobile environments
    - » Emerald (Jul), Corba (Vinoski)
- Process Migration
  - Able to remotely execute arbitrary parts of an application
  - Difficult to use and not meant for mobile environments
    - » Amoeba (Tanenbaum), Sprite (Ousterhout), Java RMI (SUN)
- Declarative Languages
  - More generic languages to solve a wider range of problems
    - » 4GLs (Martin), Little languages (Bentley)

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Related Work (Cont)

Software Engineering

- Reusing techniques in a new domain

- Stub generators
  - RPC (Birrell, Nelson)
- Methodology
  - Software Modularity (Parnas)

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Expected Contributions

- Concept of tactics for abstracting remote partitions of an application
- Design of a tactics-based remote execution system
- Set of tools and methods to ease application development time
- Validation and demonstration using multiple real applications

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Publications

- *"Tactics-Based Remote Execution for Mobile Computing"*, R. K. Balan, M. Satyanarayanan, S. Park, T. Okoshi, Proceedings of the 1st USENIX International Conference on Mobile Systems, Applications, and Services (MobiSys), San Francisco, California, USA, May 2003.
- *"The Case for Cyber Foraging"*, R. K. Balan, J. Flinn, M. Satyanarayanan, S. Sinnamohideen, H. Yang, In Proceedings of the 10th ACM SIGOPS European workshop, Saint-Emilion, France, September 2002.
- *"Meeting the Software Engineering Challenges of Adaptive Mobile Applications"*, R. K. Balan, J. P. Sousa, M. Satyanarayana, Technical Report, CMU-CS-03-111, Carnegie Mellon University, February, 2003.

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