# e-Merge-ANT: Spring 2001

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- Status
- Architecture
  - decentralized resource management through graph coloring
- Soft graph coloring algorithms
  - decentralized, iterative-repair, anytime, approximate colorers
- Experimental results
  - dynamics, problem complexity, scalability, robustness

# Status

Previous Results

Framework for distributed
resource management
as scheduling

Algorithm for
distributed scheduling:
Self-Induced Colorer

Challenge problem
demo on
simulator & hardware

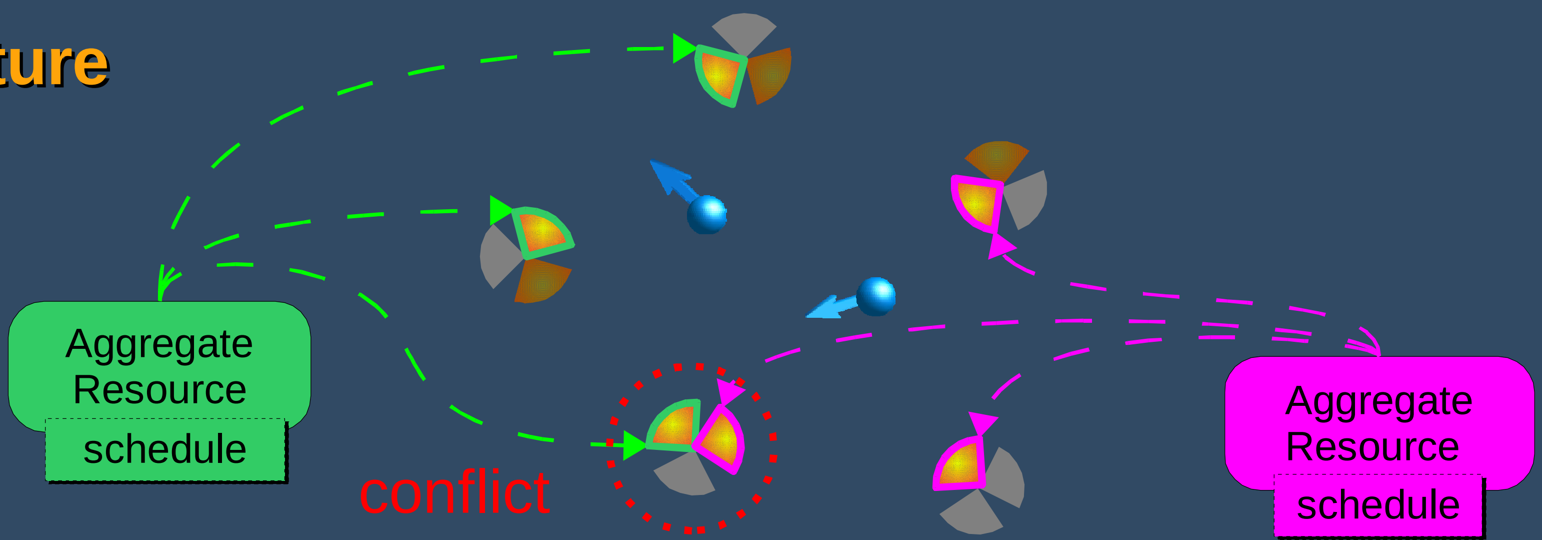
New Results

Framework for assessing performance
Experimental investigation of performance
Faster, cheaper algorithms:
Fixed-Probability Colorer &
Conservative Fixed-Probability Colorer
Initial theoretical analysis of performance
Visualization

Autumn *Demo*

Integrate new algorithms
with hardware & new simulator

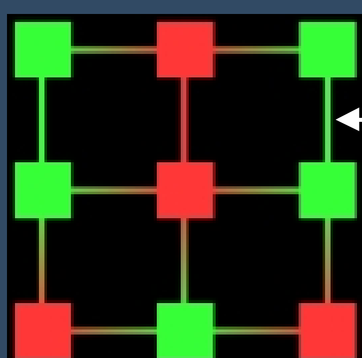
# Architecture




- Three sensors must collaborate to triangulate a target
  - define *aggregate sensors* representing “triangulators”
- Aggregate sensors may share physical radar units
  - each physical radar unit contains three heads
  - constraint: only one head can be sampled at a time
  - each radar unit may service several aggregate sensors
- A sampling *conflict* may occur
  - when two or more aggregate sensors try to use the same radar unit simultaneously
- Avoid conflicts by scheduling
  - assign time slots for aggregate sensors to use samplers

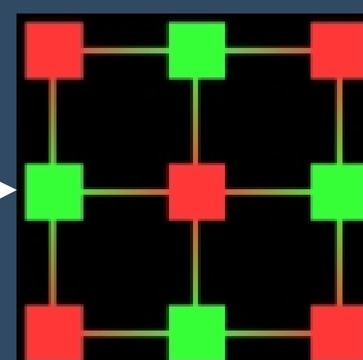
# Scheduling as Graph Coloring

| Challenge Problem | Resource Management | Graph Coloring |
| --- | --- | --- |
| aggregate sensors | resources | nodes |
| sample only one head per unit | mutual exclusion constraints | edges |
| time slots | reservations | colors |
| feasible scan schedule | feasible schedule | proper coloring |
| minimum scan period | minimum feasible schedule length | chromatic number |



a conflict

a proper 2-coloring



# Decentralized Graph Coloring

- Each node is to choose its own color
- Iterative algorithms:
  - begin with a random coloring
  - iteratively improve
    - each node chooses a color that minimizes its conflicts with its neighbors
- Need to coordinate choice of colors
  - if two neighbors simultaneously choose colors, they may choose the same color
  - i.e., they may introduce a conflict
- Number of colors fixed in advance
  - e.g., by considering latency constraints
    - scan range, speed of target, measurement duration

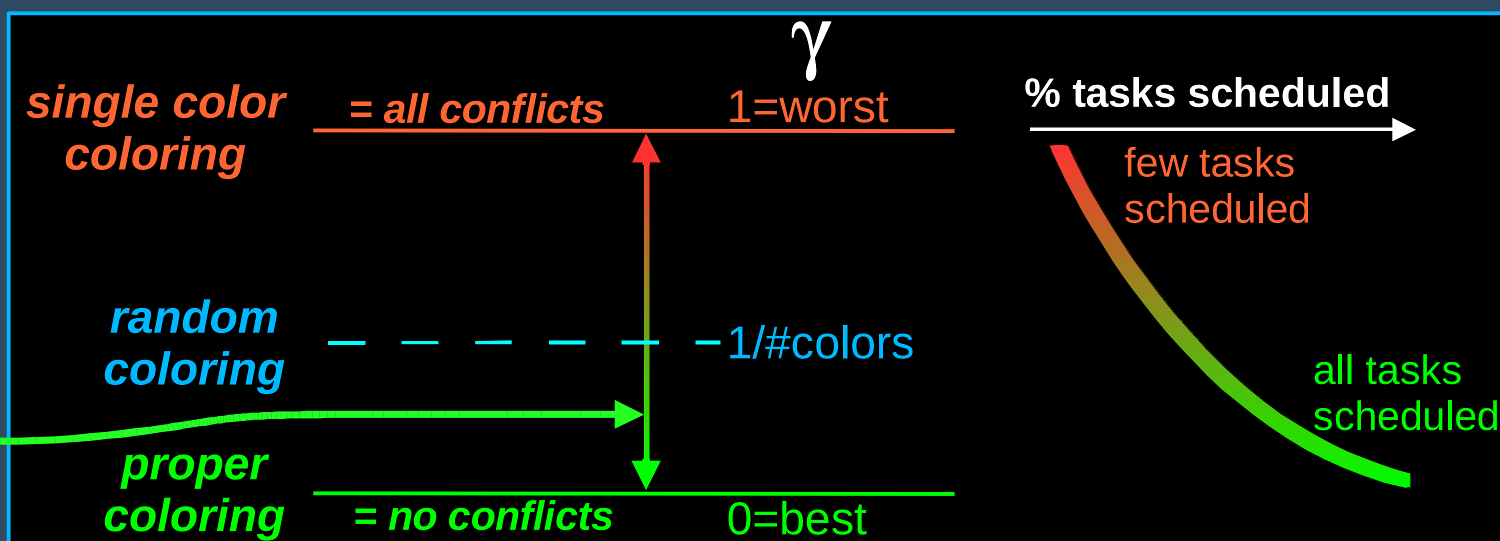
# Old Algorithm: Self-Induced Colorer

- Previously, we used *self-induced* coloring to coordinate color choices (to reduce the introduction of conflicts)
  - a node chooses a color for itself only when its *current* color is “active”
- Demoed with simulator/hardware
  - gave good performance in challenge problem simulator
- Missing: quantitative evaluation for large graphs ...

# Soft Graph Coloring

- Generalize the metric on colorings from proper/non-proper to ..
- *Degree of conflict* $\gamma$
  - $\gamma$ = (number of conflicts)/(total number of edges)
    - range is [0,1]: 0 is best, 1 is worst
  - independent of graph size
  - suitable metric for off-line analysis of progress of anytime colorer
    - a random coloring with C colors has an expected score of $\gamma$=1/C
      - this acts as a baseline for assessing algorithms
  - applicable even in over-constrained scenarios
    - e.g., 3-coloring a 4-colorable graph

*Need to do better than random!*



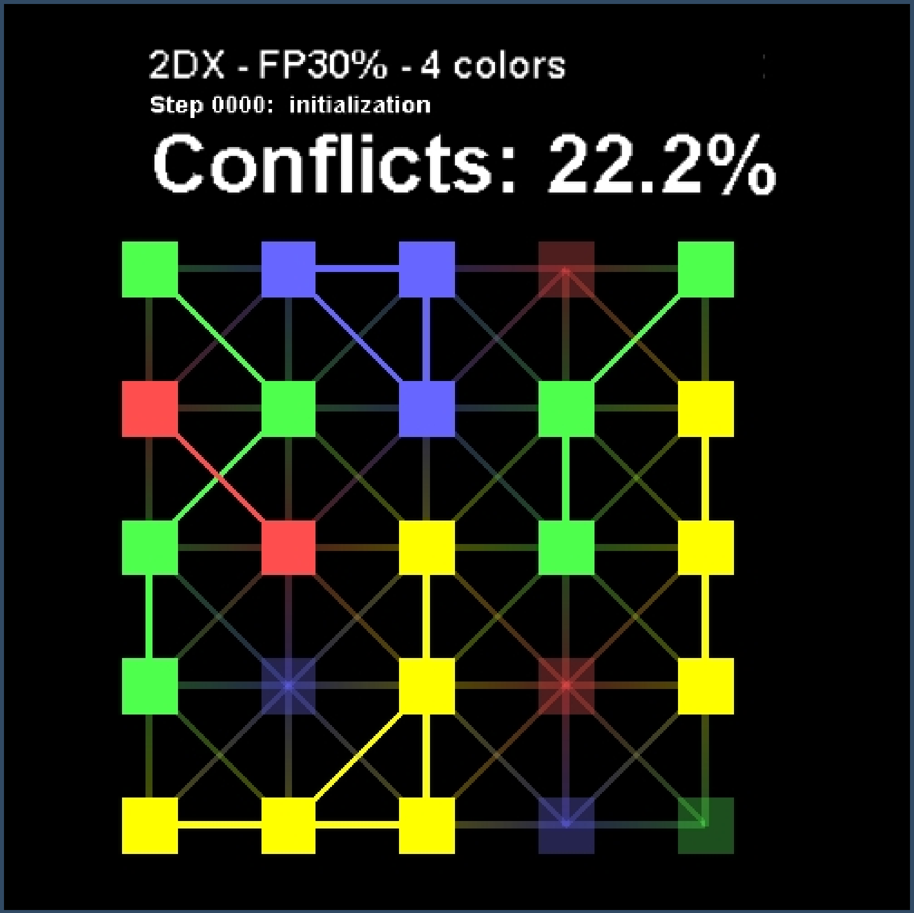
# New Algorithm: Fixed-Probability Colorer

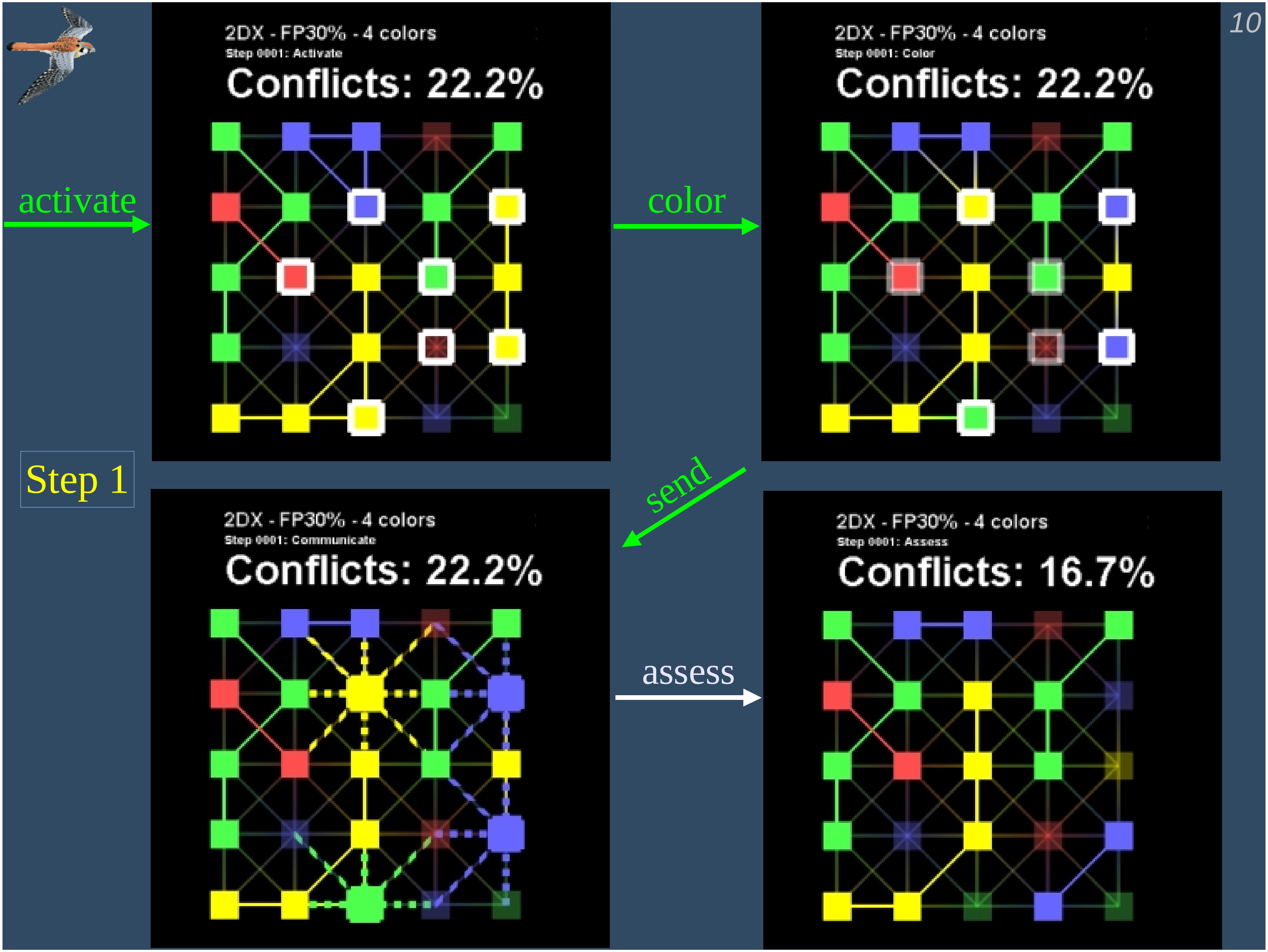
- FP is a soft graph colorer
  - decentralized, iterative, anytime, local-repair algorithm
- Iterated, synchronized steps, each having three phases:
  a. Probabilistic activation:
     - at each step, each node activates at random with a fixed, uniform probability (the *activation probability*)
     - in contrast, in SI, nodes activate color by color
       - SI is less likely to introduce conflicts than FP but has lower parallelism
  b. Select color using local repair/optimization:
     - when a node activates, it chooses a color that minimizes its conflicts with its neighbors
       - based on its current knowledge of its neighbors' colors
  c. Local communication:
     - when a node changes color, it informs its neighbors

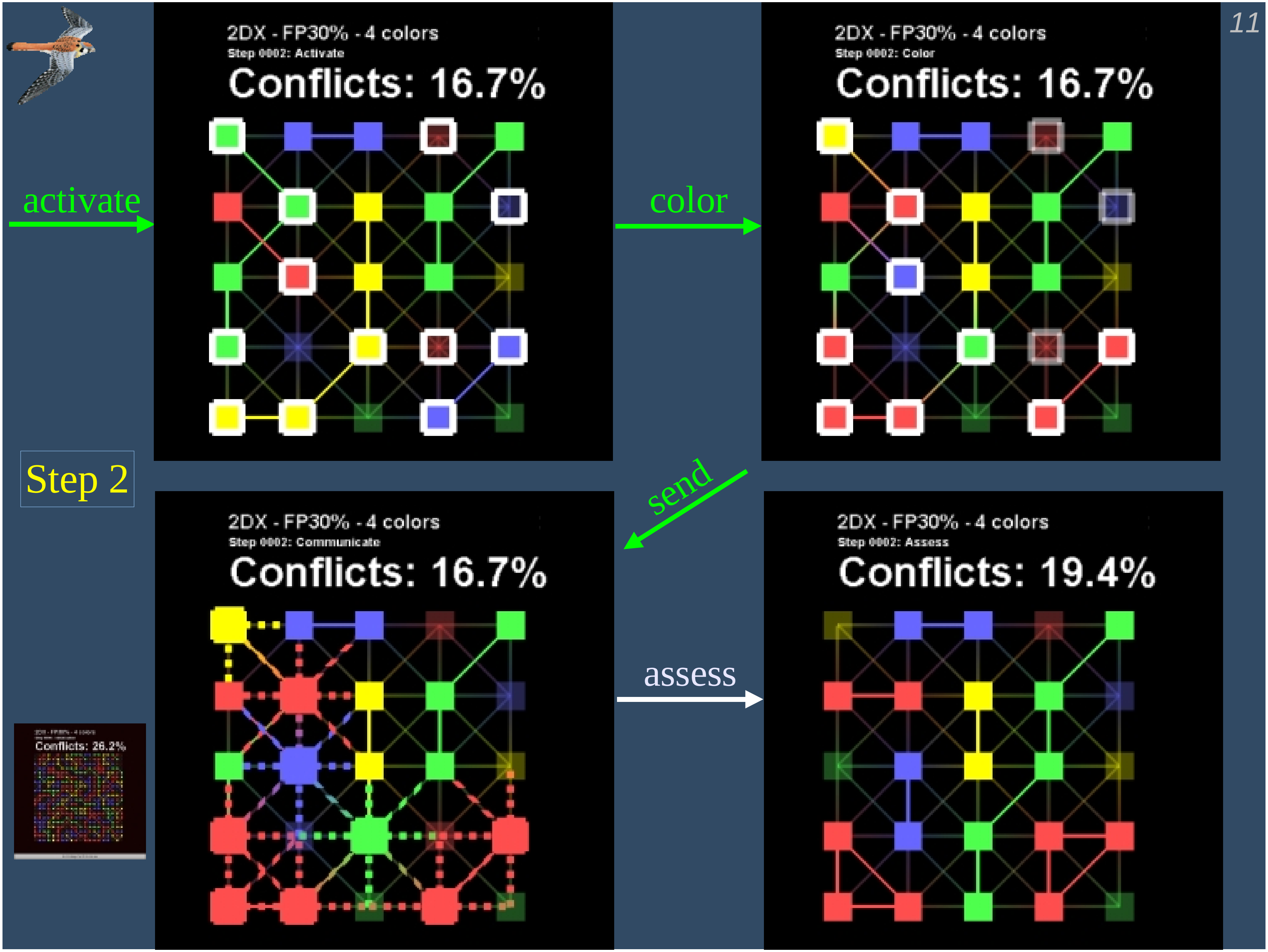
# The FP Algorithm At Work

Initialization

- 4 colors
- Topology:
  - each non-boundary node has 8 neighbors
- Edges:
  - bright = a conflict
  - faded = not a conflict
- Nodes:
  - bright = some incident edges are conflicts
  - faded = no incident edge is a conflict

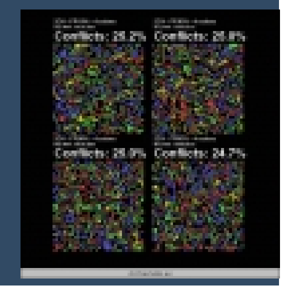



activate
color
send
assess
Step 1
2DX - FP30% - 4 colors
Step 0001: Activate
Conflicts: 22.2%
2DX - FP30% - 4 colors
Step 0001: Color
Conflicts: 22.2%
2DX - FP30% - 4 colors
Step 0001: Communicate
Conflicts: 22.2%
2DX - FP30% - 4 colors
Step 0001: Assess
Conflicts: 16.7%

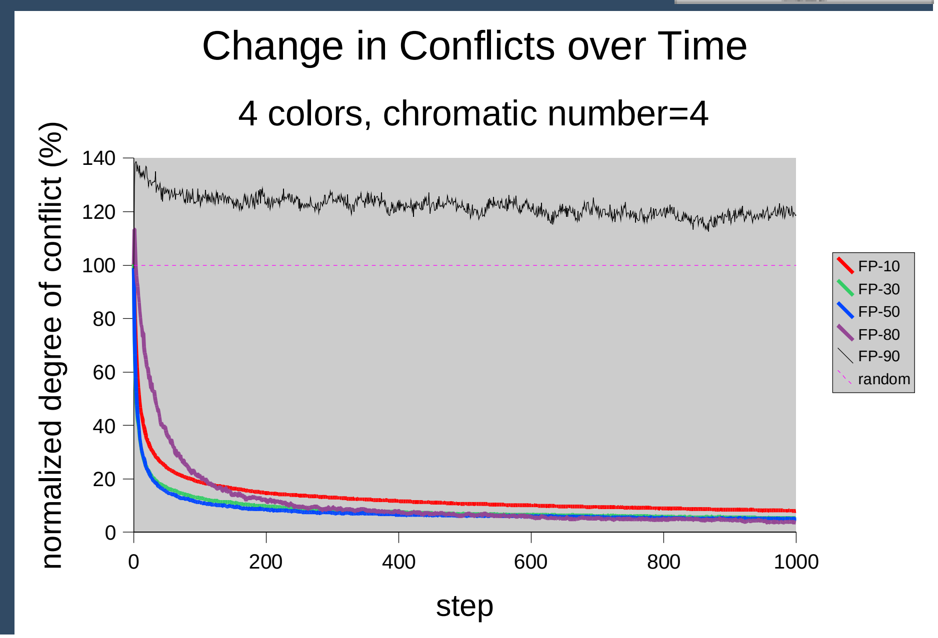

activate
2DX - FP30% - 4 colors
Step 0002: Activate
Conflicts: 16.7%
color
2DX - FP30% - 4 colors
Step 0002: Color
Conflicts: 16.7%
Step 2
send
2DX - FP30% - 4 colors
Step 0002: Communicate
Conflicts: 16.7%
assess
2DX - FP30% - 4 colors
Step 0002: Assess
Conflicts: 19.4%
Conflicts: 26.2%

# Convergence: Typical Behaviors

- FP converges rapidly for wide range of activation probabilities
  - 30% seems to be a good choice for a wide range of graphs
- If the activation probability is too high, FP does not converge
  - neighbors simultaneously update colors (introducing conflicts)
  - more complex graphs require lower activation probabilities
- If the probability is too low, FP converges too slowly
  - in particular, early reduction of conflicts is slow
- Need to balance speed against convergence

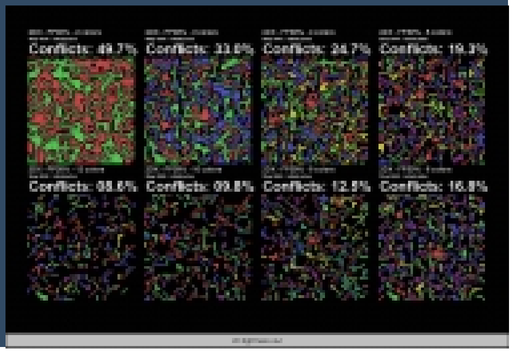


- *Normalized degree of conflict* $\Gamma = \gamma C$
  - coloring is easier with more colors
  - scale $\gamma$ by the number of colors C
  - simplifies analysis of experimental data
  - a random coloring has an expected value of $\Gamma$ of 1



# Problem Complexity: Constraint Tightness

- The chromatic number seems to be a critical threshold for problem complexity
- FP performs “well” when critically or slightly under-constrained
  - #colors equal to or slightly greater than chromatic number
  - FP usually achieves proper coloring when under-constrained
- FP performs “reasonably” & *behaves* well when over-constrained
  - #colors<chromatic number
  - reduces conflicts significantly below random level
  - doesn’t fall down & doesn’t blow up
- FP’s performance when loosely-constrained is counter-intuitive
  - performance is not as good as might be expected on easy problems

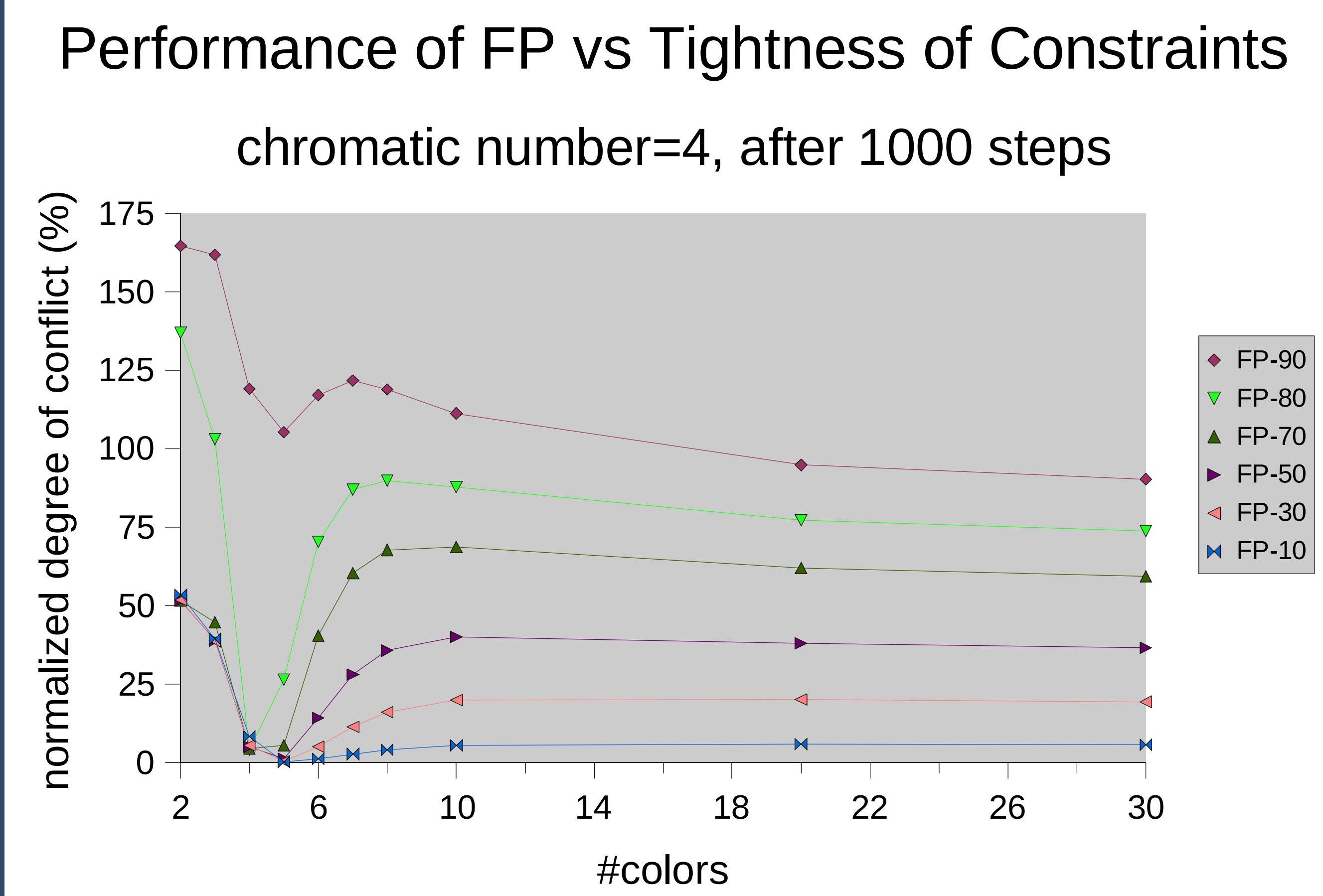


# Performance of FP against Activation Prob. & #Colors

- When loosely constrained, FP partly acts like a random colorer
  - most colors are unused in a given neighborhood
  - a node chooses randomly from the unused colors
  - so at every activation, a node is highly likely to change color

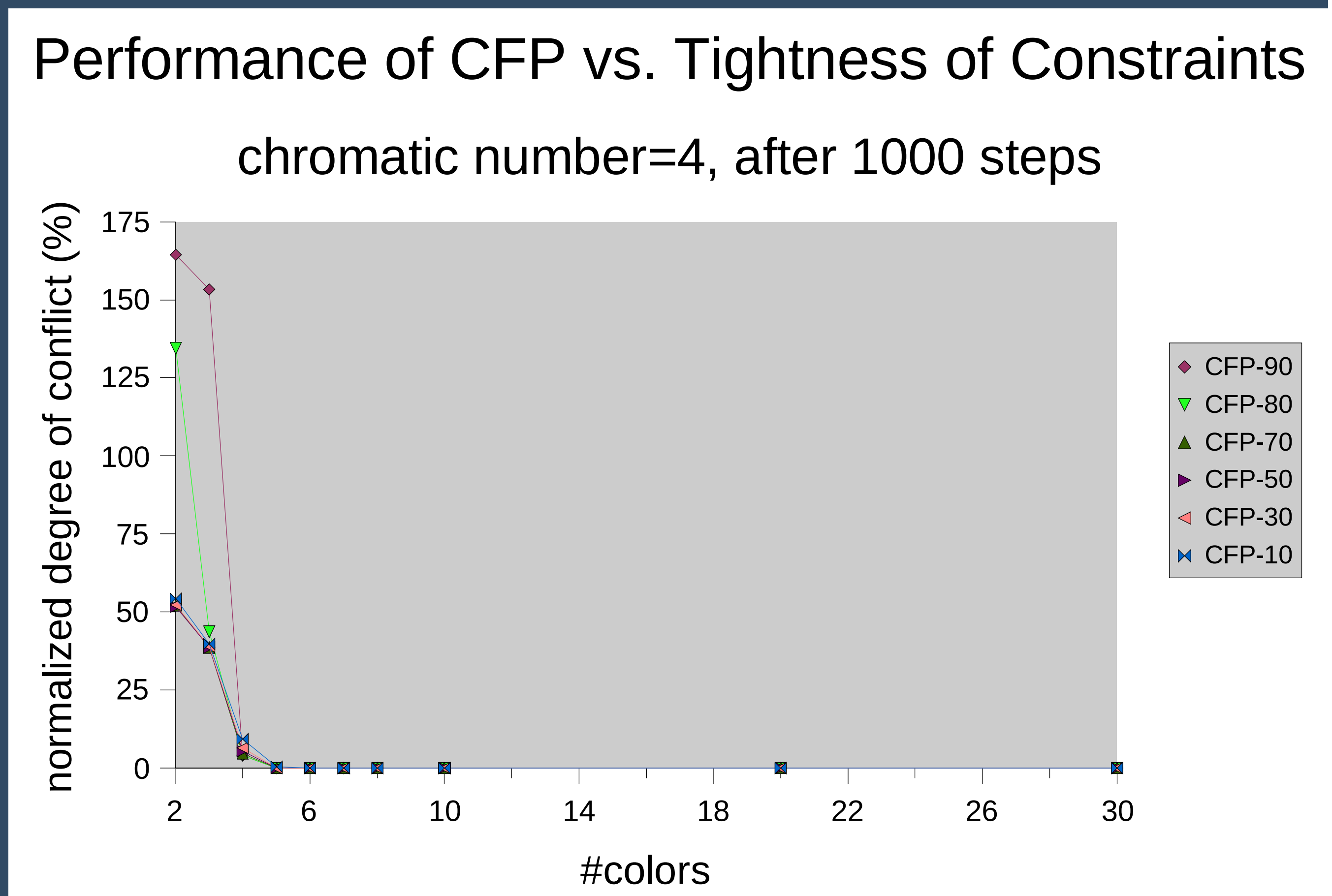
**Loosely constrained FP**

- $\Gamma$ does **not** converge to zero
- simple analysis predicts $\Gamma \to C\sigma\theta/(2-\theta)$
  - C is the number of colors
  - $\theta$ is the activation threshold
  - $\sigma$ is the probability that two neighbors will choose the same color if they activate simultaneously
- experiments give a good fit for $\sigma=1/(C-C_0)$
  - $C_0$ is the chromatic number



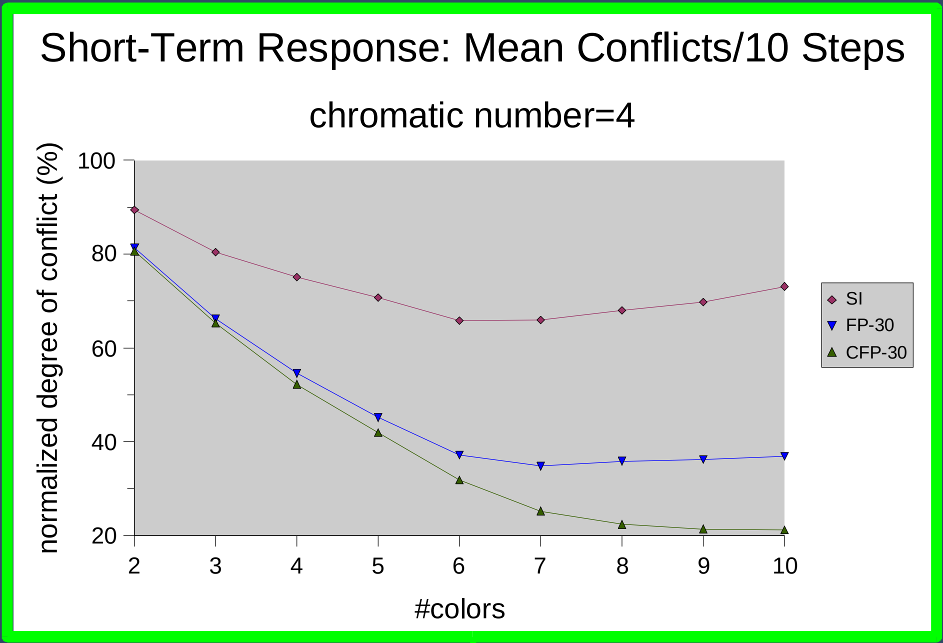
# New Algorithm: Conservative Fixed-Probability Colorer

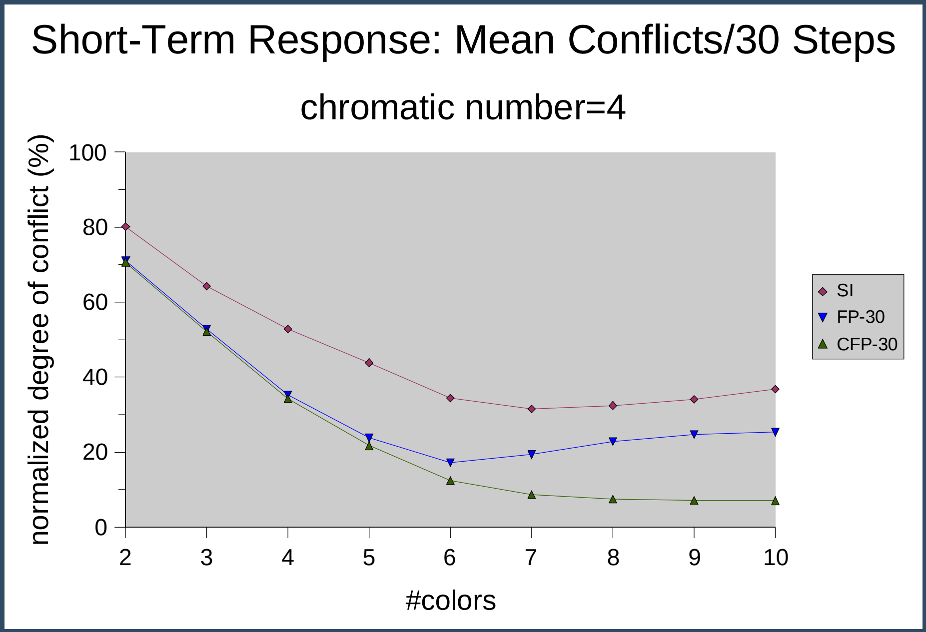
- CFP is a more "conservative" variant of FP
  - now an activated node will change color only if it has conflicts with its neighbors
- CFP has better performance when under/loosely-constrained
  - proper coloring rapidly achieved

# Short-Term Response: Conflicts

- CFP quickly reduces conflicts when critically constrained, under-constrained or loosely constrained
  - ⇒ adaptation to changing tasks/resources
  - – CFP is an *anytime* algorithm
    - tracking proceeds simultaneously with coloring
    - appropriate metric: the *mean* of the degree of conflict
- CFP reduces conflicts below random when over-constrained



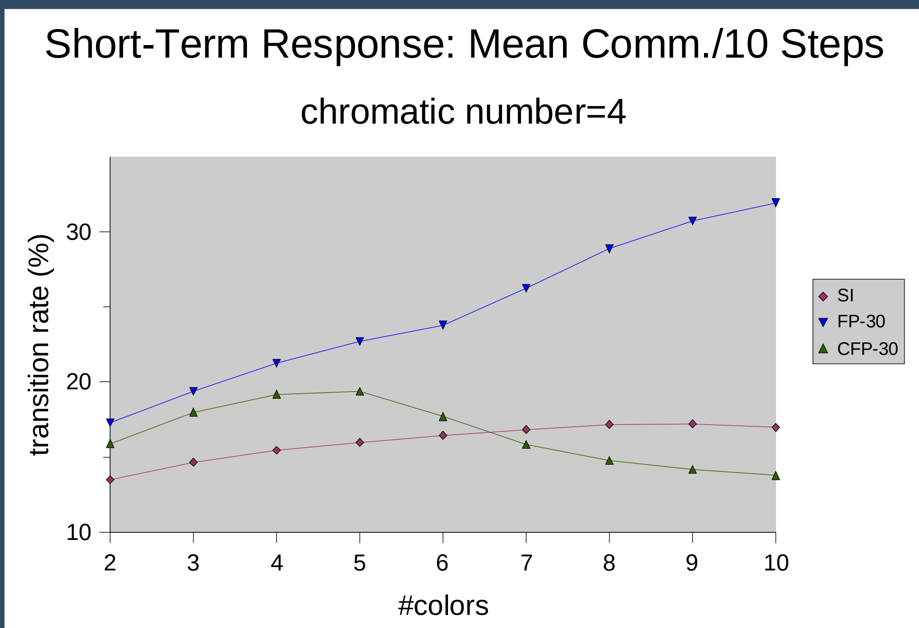



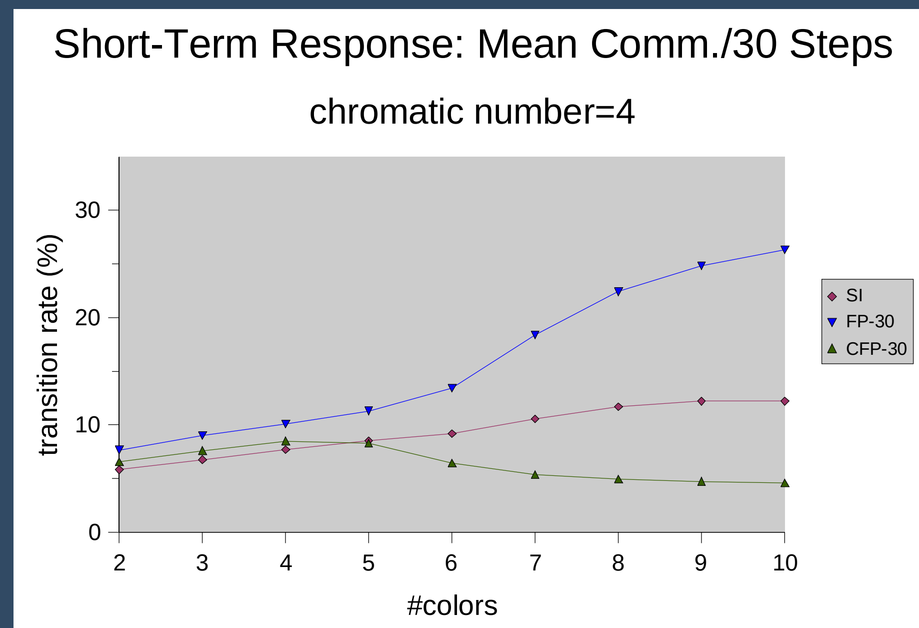

*for the challenge problem*

# Short-Term Response: Communication

- CFP has low communication costs

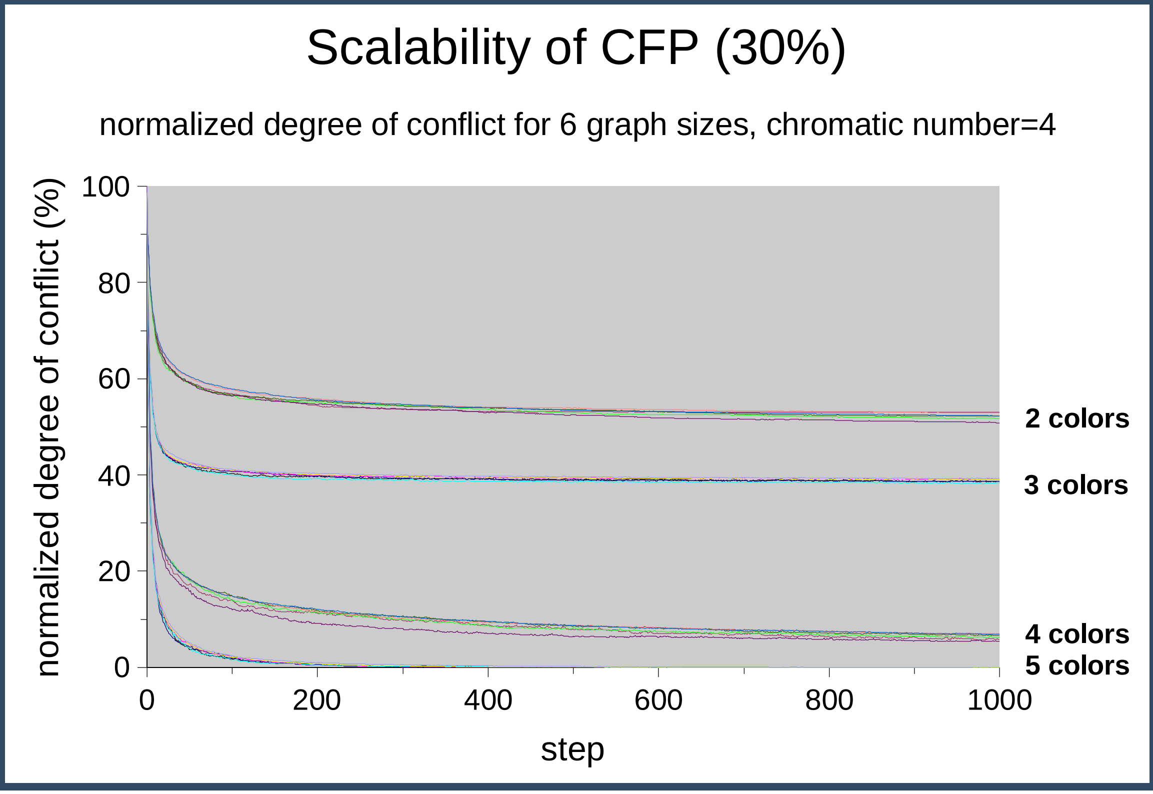
- For a single step, the transition rate $\tau$ is the fraction of nodes that change color
  - $\tau$ is independent of the interconnection complexity of the graph
  - it simplifies comparison of experimental data over multiple graphs



# Scalability

- CFP is scalable
  - per-node costs are independent of the number of nodes
  - per-node communication, storage & computation costs proportional to number of neighbors, not number of nodes
- Rate of conflict reduction for CFP is independent of graph size
  - for large graphs of similar structure, degree of conflict does not vary much with graph size




For each color, plot shows results for 6 graphs averaged over 3 runs per graph

- 625 nodes
- 900 nodes
- 1000 nodes
- 1520 nodes
- 3600 nodes
- 4970 nodes

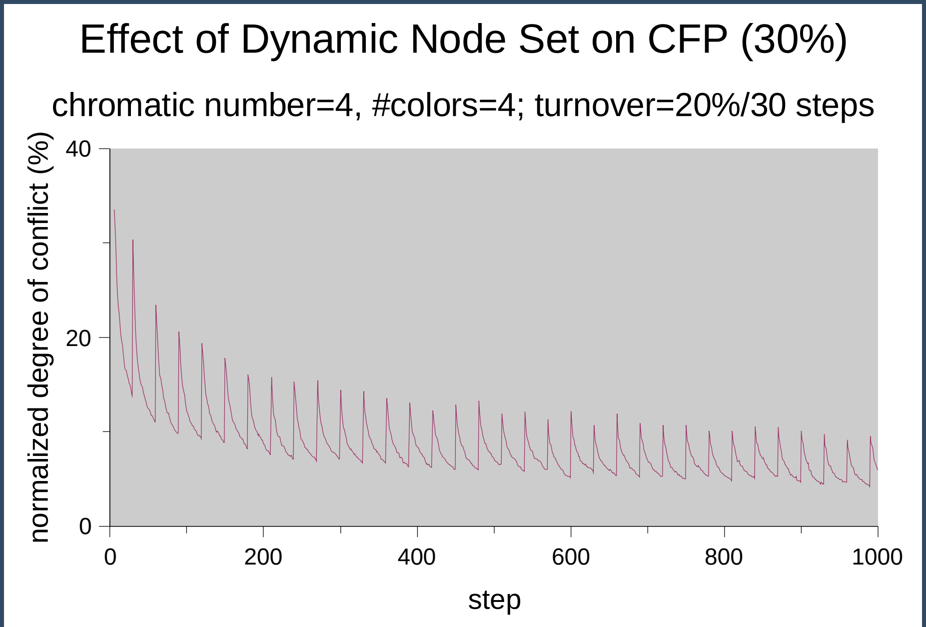
# Fault Tolerance – Dynamic Topology

- CFP gracefully adapts to faulty nodes
  - low rates of node turnover, applied continuously, slightly reduce the quality of colorings
  - CFP recovers robustly from moderate rates of node turnover applied intermittently
    - number of conflicts jumps, but quickly falls
- Tested using a simple scheme to simulate a dynamic hardware configuration (e.g., nodes dying and reviving)
  - varies the topology without drastically altering the complexity (i.e., the chromatic number)
  - simplifies analysis

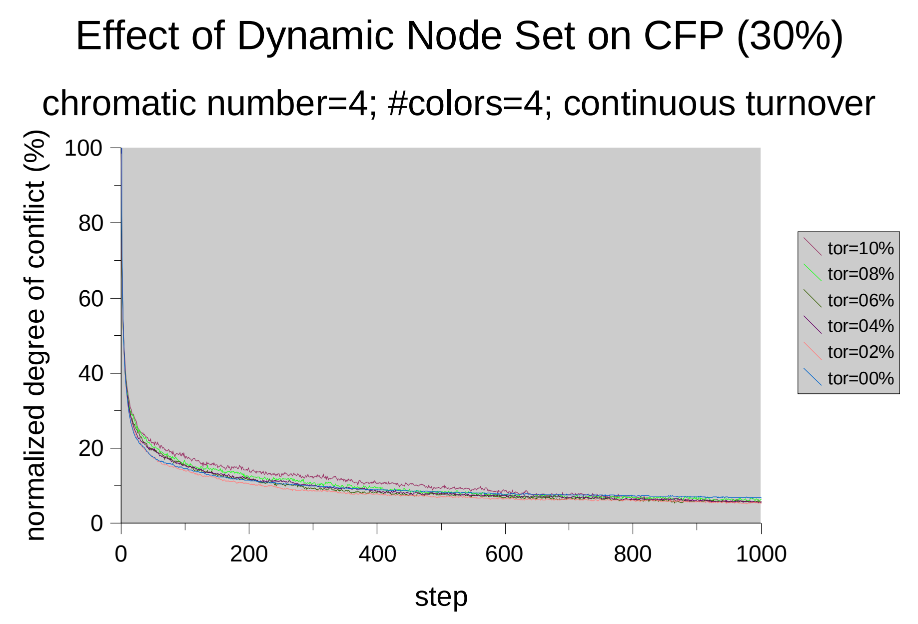
- Construct a graph
- Remove R randomly-chosen nodes (and incident edges)
- Every P steps
  - remove a further R randomly-chosen nodes (and incident edges)
  - from the pool of 2R removed nodes, reinsert R randomly choosen nodes
  - reinsert all previously removed edges whose end nodes are now present in the graph

# Dynamic Topology – Effect

Intermittent:
turnover rate R=20%
applied every 30 steps

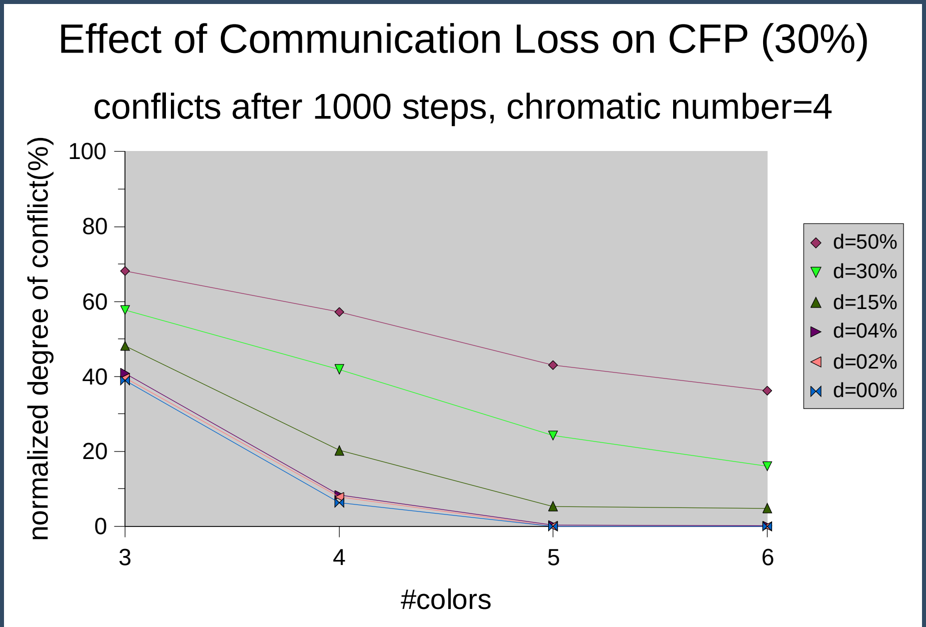


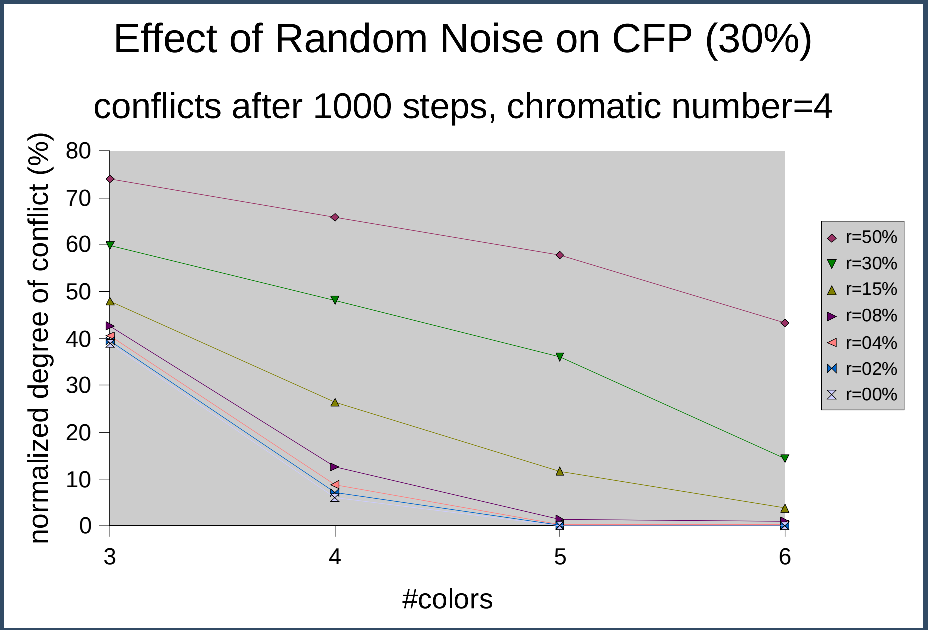

Continuous:
turnover applied
every step



# Communication Noise and Loss

- CFP is tolerant of (low-level) communication noise and loss
  - low-level noise or lossiness increases the degree of conflict incrementally
- Model communication noise as follows:
  - each color-change message is subjected to a random process:
    - with probability d, the message is dropped
    - with probability r, the color is randomized
    - with probability 1-d-r, the message is passed through unaltered



# Summary of Results for CFP (*et al.*)

- Theoretical models
  - convergence when under-constrained
  - convergence when critically constrained
  - loose upper-bound on communication costs
  - scalability (constant parallel complexity)
- Experimental results
  - reasonable activation probability for wide range of graphs
  - convergence
  - rapid short-term reduction in conflicts when under-constrained
  - rapid short-term reduction in conflicts when critically constrained
  - good behavior when over-constrained
  - low communication costs
  - scalability
  - robustness against node/communication failure
- Simple algorithm for decentralized, anytime graph coloring
  - promises fast, cheap, robust resource management

# Future Work

- Does “fast” translate into “fast enough”?
  - need to test algorithm on challenge problem
  - other resource types may give more complex search spaces and may need more complex interaction between schedulers
- Application-specific models of performance
  - explicit relationship between $\gamma$ and “quality of solution”
- Different classes of local, iterative-repair algorithm
  - e.g., activation based on local measures of degree of conflict
    - measures maintained by diffusion scheme
  - dynamic determination of chromatic number & #colors
    - we already have prototype algorithm
- Open problems (for dynamics/complexity groups?):
  - reliable performance predictors from simple graph metrics
    - e.g., chromatic number, degree of interconnection
    - metrics need to be locally & cheaply computable for use at run-time
  - convergence models for over-constrained coloring
  - improved analysis $\rightarrow$ improved algorithms