ISCAS 中国科学院软件研究所 Institute of Software Chinese Academy of Sciences | 智能软件研究中心 Intelligent Software Research Center

V8 Turbofan:
从字节码到SON图-part2

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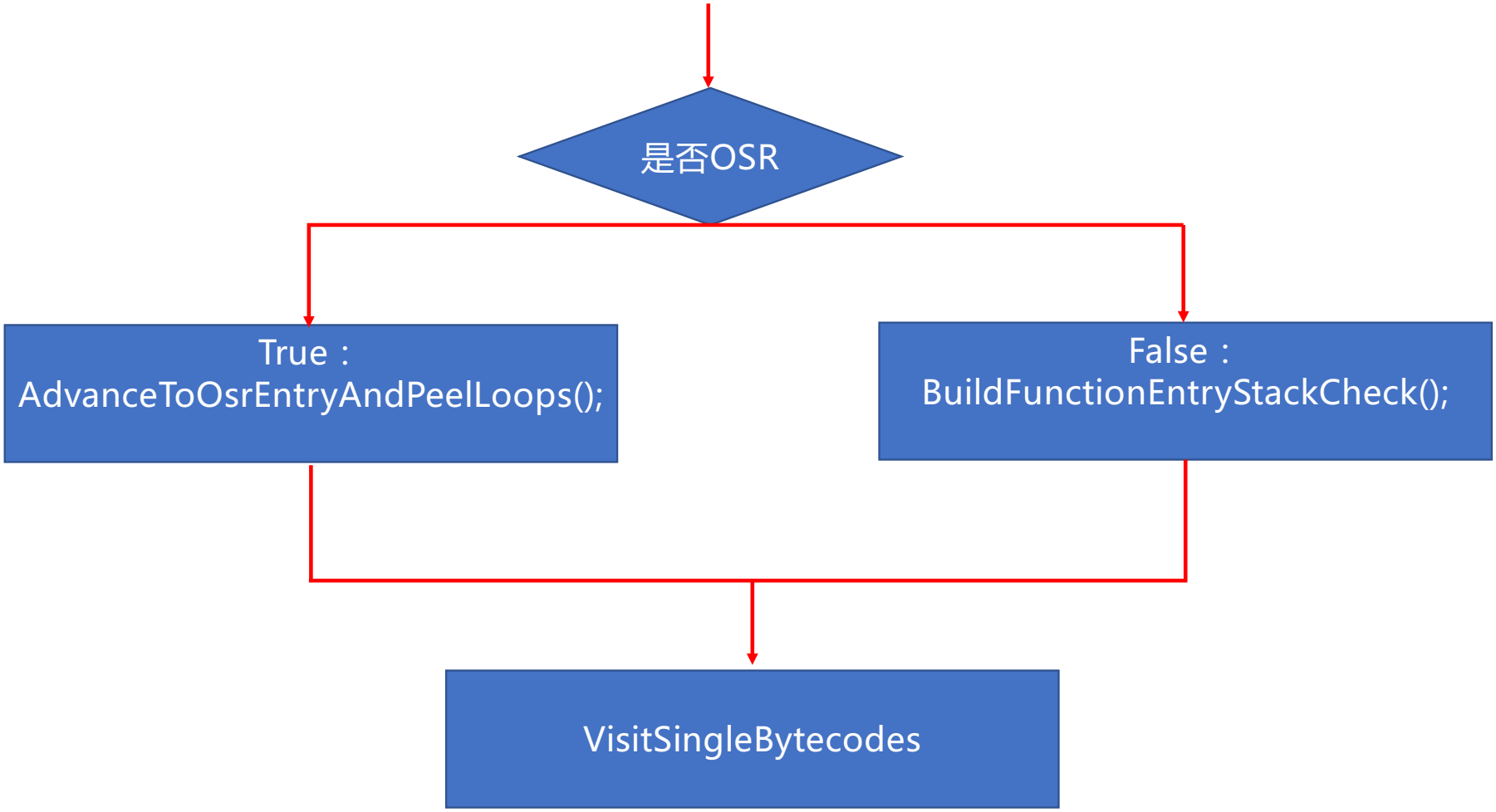
从Bytecode到SON图的构建：内容大纲

- Demo case 及其 Graph
- 总体构建流程概述
- Step by Step, Node by Node讲述图的构建过程
    1. new and set the Start node
    2. new Environment and set_environment
    3. CreateFeedbackCellNode
    4. CreateFeedbackVectorNode
    5. MaybeBuildTierUpCheck
    6. CreateNativeContextNode
    7. VisitBytecodes: one by one
    8. new and set the End node

Step by Step, Node by Node讲述图的构建过程

1. new and set the Start node
2. new Environment and set_environment
3. CreateFeedbackCellNode
4. CreateFeedbackVectorNode
5. MaybeBuildTierUpCheck
6. CreateNativeContextNode
7. VisitBytecodes: one by one
8. new and set the End node

Step7：VisitBytecodes整体流程



Step7：VisitBytecodes整体代码

@src/compiler/bytecode-graph-builder.cc

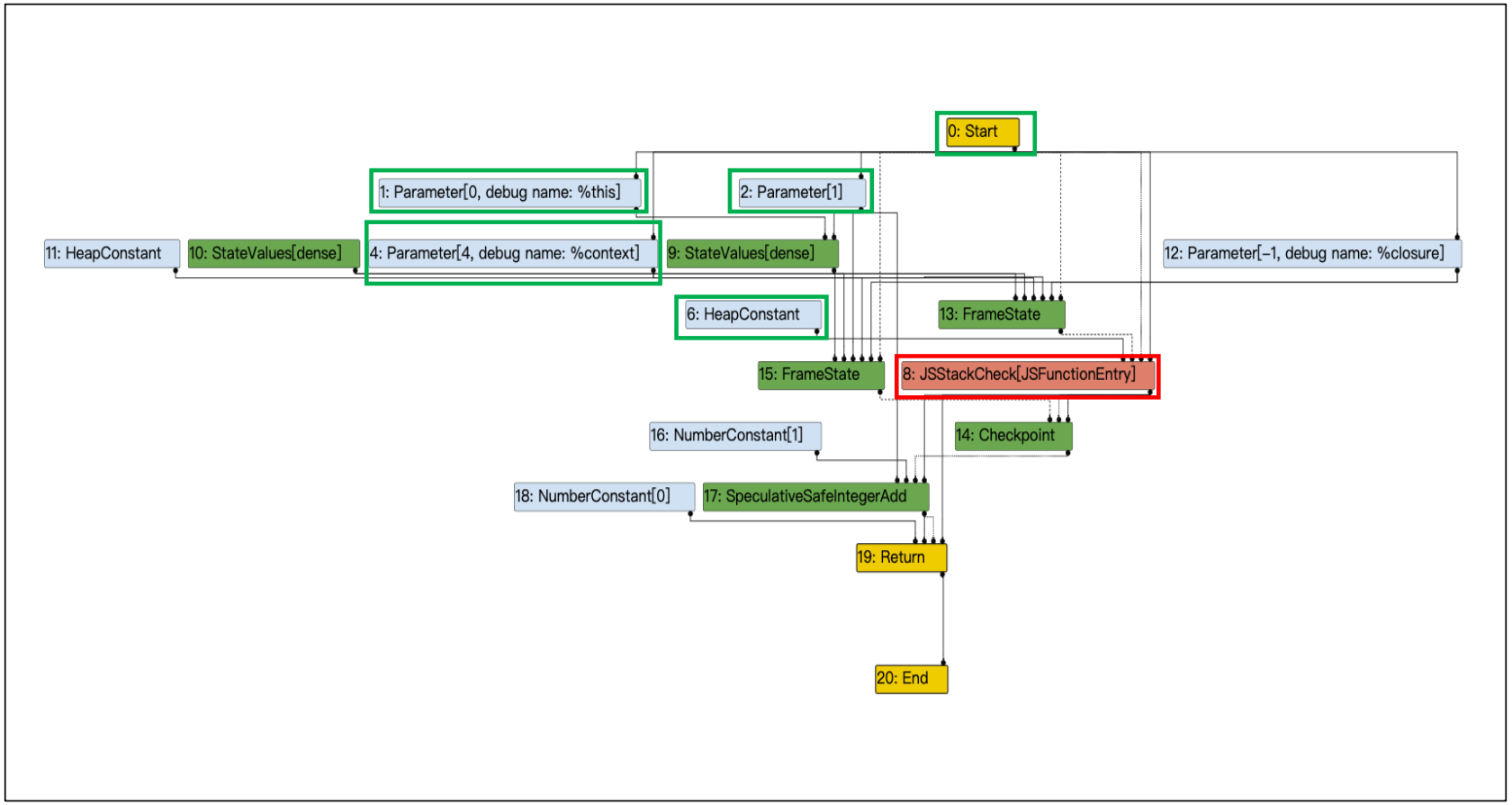
```
void BytecodeGraphBuilder::VisitBytecodes() {
  if (osr_) {
    // We peel the OSR loop and any outer loop containing it except that we
    // leave the nodes corresponding to the whole outermost loop (including
    // the last copies of the loops it contains) to be generated by the normal
    // bytecode iteration below.
    AdvanceToOsrEntryAndPeelLoops();
  } else {
    BuildFunctionEntryStackCheck(); //Step7.1： test函数要整体被JIT，不属于OSR
  }
  for (; !bytecode_iterator().done(); bytecode_iterator().Advance()) {
    VisitSingleBytecode(); //Build每一个Bytecode
  }
}
```

Step7.1: BuildFunctionEntryStackCheck

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::BuildFunctionEntryStackCheck() {
  if (!skip_first_stack_check()) {
    DCHECK(exception_handlers_.empty());
    Node* node =
        NewNode(javascript()->StackCheck(StackCheckKind::kJSFunctionEntry)); //生成StackCheck节点，
StackCheck节点有一个输入是FrameState，现在先把FrameState输入设置成一个Dead节点
    PrepareFrameStateForFunctionEntryStackCheck(node);
  }
}
```

已构建完成的节点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15: FrameState
8: JSStackCheck[JSFunctionEntry]
16: NumberConstant[1]
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18: NumberConstant[0]
17: SpeculativeSafeIntegerAdd
19: Return
20: End

节点列表

0	Start	
1	Parameter	*this
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5	HeapConstant	指向FeedBackVector
6	HeapConstant	nativecontext
7	Dead	JSStackCheck的一个Dummy输入
8	JSStackCheck	

Step7.2: PrepareFrameStateForFunctionEntryStackCheck

@src/compiler/bytecode-graph-builder.cc

```
void PrepareFrameStateForFunctionEntryStackCheck(Node* node) {
    return PrepareFrameState(node, OutputFrameStateCombine::Ignore(),
                             BytecodeOffset(kFunctionEntryBytecodeOffset),
                             bytecode_analysis().GetInLivenessFor(0));
  }
```

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::PrepareFrameState(
    Node* node, OutputFrameStateCombine combine, BytecodeOffset bailout_id,
    const BytecodeLivenessState* liveness) {
  if (OperatorProperties::HasFrameStateInput(node->op())) {
    Node* frame_state_after = environment()->Checkpoint(bailout_id, combine, liveness); //Step7.3
    NodeProperties::ReplaceFrameStateInput(node, frame_state_after);
  }
}
```

Step7.3: environment()->Checkpoint

@src/compiler/bytecode-graph-builder.cc

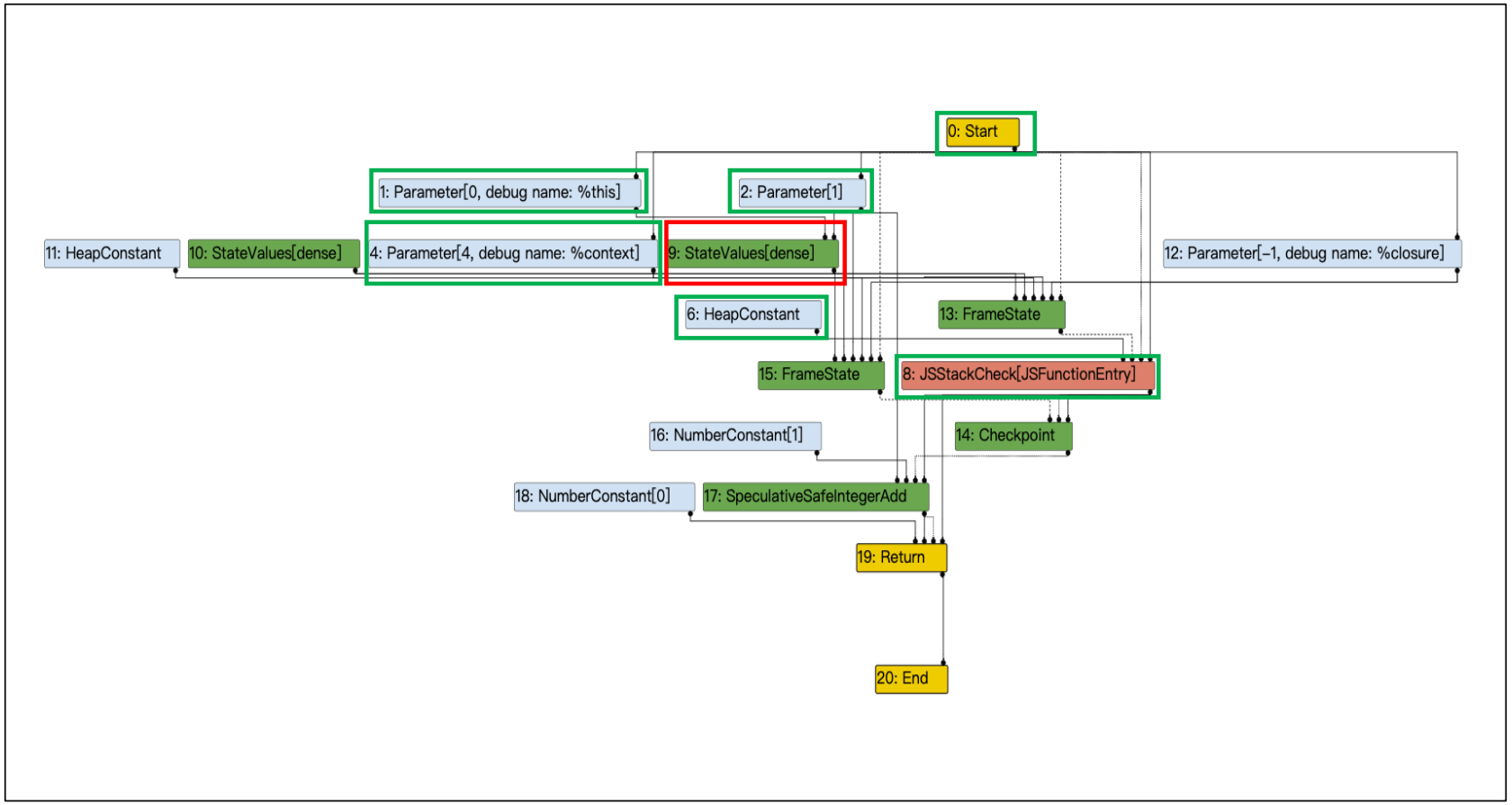
```
Node* BytecodeGraphBuilder::Environment::Checkpoint(
BytecodeOffset bailout_id, OutputFrameStateCombine combine, const BytecodeLivenessState* liveness) {
   UpdateStateValues(&parameters_state_values_, &values()->at(0), parameter_count()) ; //Step7.4: FrameState的第一个输入：parameters_state_values
   Node* registers_state_values = //FrameState的第二个输入：registers_state_values
     GetStateValuesFromCache(&values()->at(register_base()), register_count(),
                             liveness ? &liveness->bit_vector() : nullptr, 0);

   bool accumulator_is_live = !liveness || liveness->AccumulatorIsLive();
   Node* accumulator_state_value = //FrameState的第三个输入：accumulator_state_value
     accumulator_is_live && combine != OutputFrameStateCombine::PokeAt(0)
         ? values()->at(accumulator_base())
         : builder()->jsgraph()->OptimizedOutConstant();

   const Operator* op = common()->FrameState(
      bailout_id, combine, builder()->frame_state_function_info());
   Node* result = graph()->NewNode( //新建真实的FrameState节点
       op, parameters_state_values_, registers_state_values,
       accumulator_state_value, Context(), builder()->GetFunctionClosure(),
       builder()->graph()->start());
   return result;
}
```

Step7.4: parameter_state_values: UpdateStateValues

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::Environment::UpdateStateValues(Node** state_values,
                                                          Node** values, int count) {
  if (StateValuesRequireUpdate(state_values, values, count)) {
    const Operator* op = common()->StateValues(count, SparseInputMask::Dense());
    (*state_values) = graph()->NewNode(op, count, values); //新建StateValues for parameters
  }
}
```

已构建完成的节点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8	JSStackCheck	
9	StateValues	StateValues for parameter state, 作为FrameState的第一个输入

Step7.5: registers_state_values: GetStateValuesFromCache

@src/compiler/bytecode-graph-builder.cc： BytecodeGraphBuilder::Environment::Checkpoint()

```
Node* registers_state_values = //FrameState的第二个输入：registers_state_values
    GetStateValuesFromCache(&values()->at(register_base()), register_count(),
                            liveness ? &liveness->bit_vector() : nullptr, 0);
```

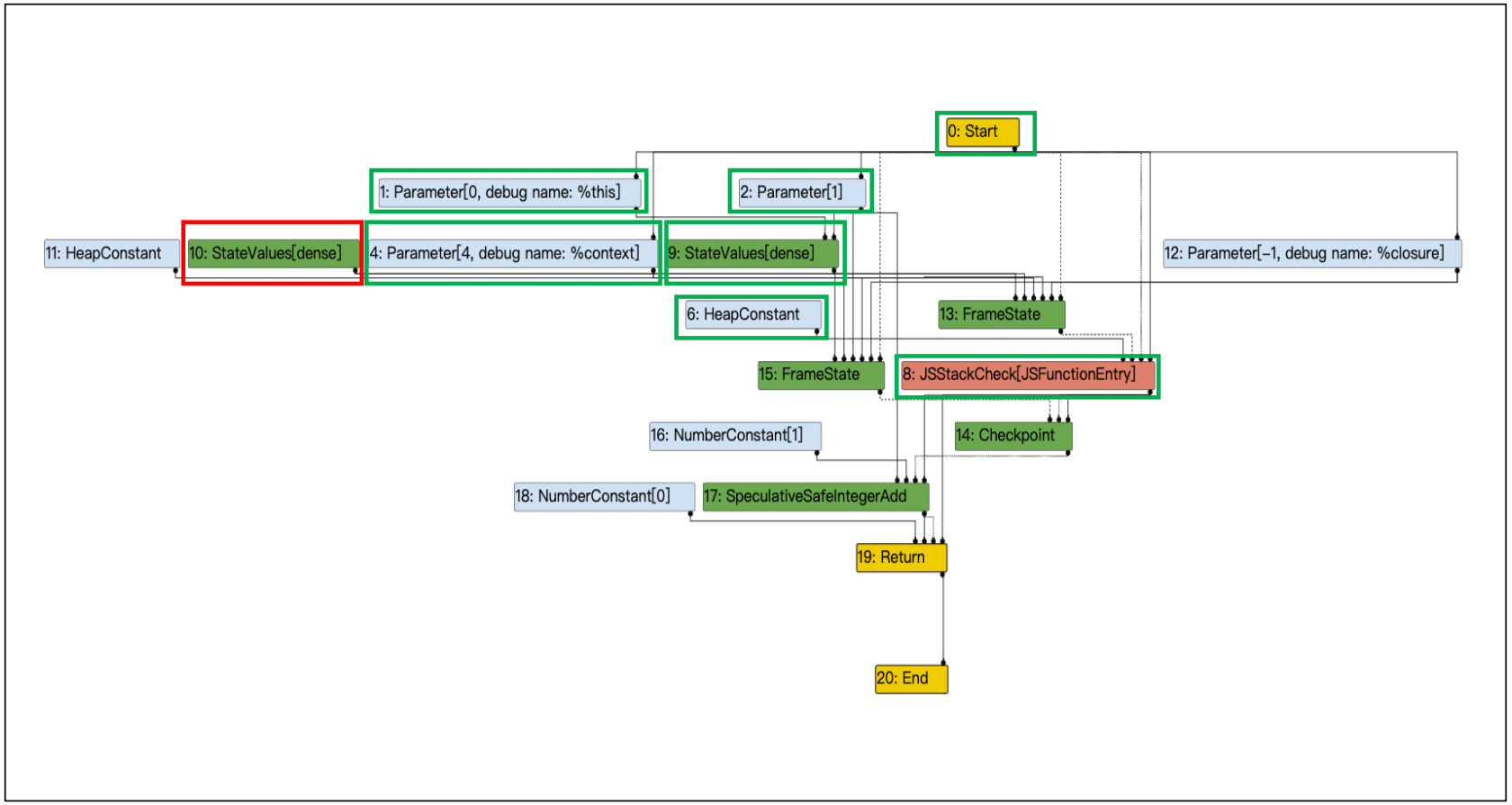
```
Node* BytecodeGraphBuilder::Environment::GetStateValuesFromCache(
    Node** values, int count, const BitVector* liveness, int liveness_offset) {
  return builder_->state_values_cache_.GetNodeForValues(
      values, static_cast<size_t>(count), liveness, liveness_offset);
}
```

Step7.5: registers_state_values: GetStateValuesFromCache

```
@ src/compiler/state-values-utils.cc

Node* StateValuesCache::GetNodeForValues(Node** values, size_t count,
                                         const BitVector* liveness,
                                         int liveness_offset) {
  if (count == 0) {
    return GetEmptyStateValues(); //test函数的register 个数是0
  }
  size_t height = 0;
  size_t max_inputs = kMaxInputCount;
  while (count > max_inputs) {
    height++;
    max_inputs *= kMaxInputCount;
  }
  size_t values_idx = 0;
  Node* tree = BuildTree(&values_idx, values, count, liveness, liveness_offset, height); //构建树状结构的
节点cache
  return tree;
}
```

已构建完成的节点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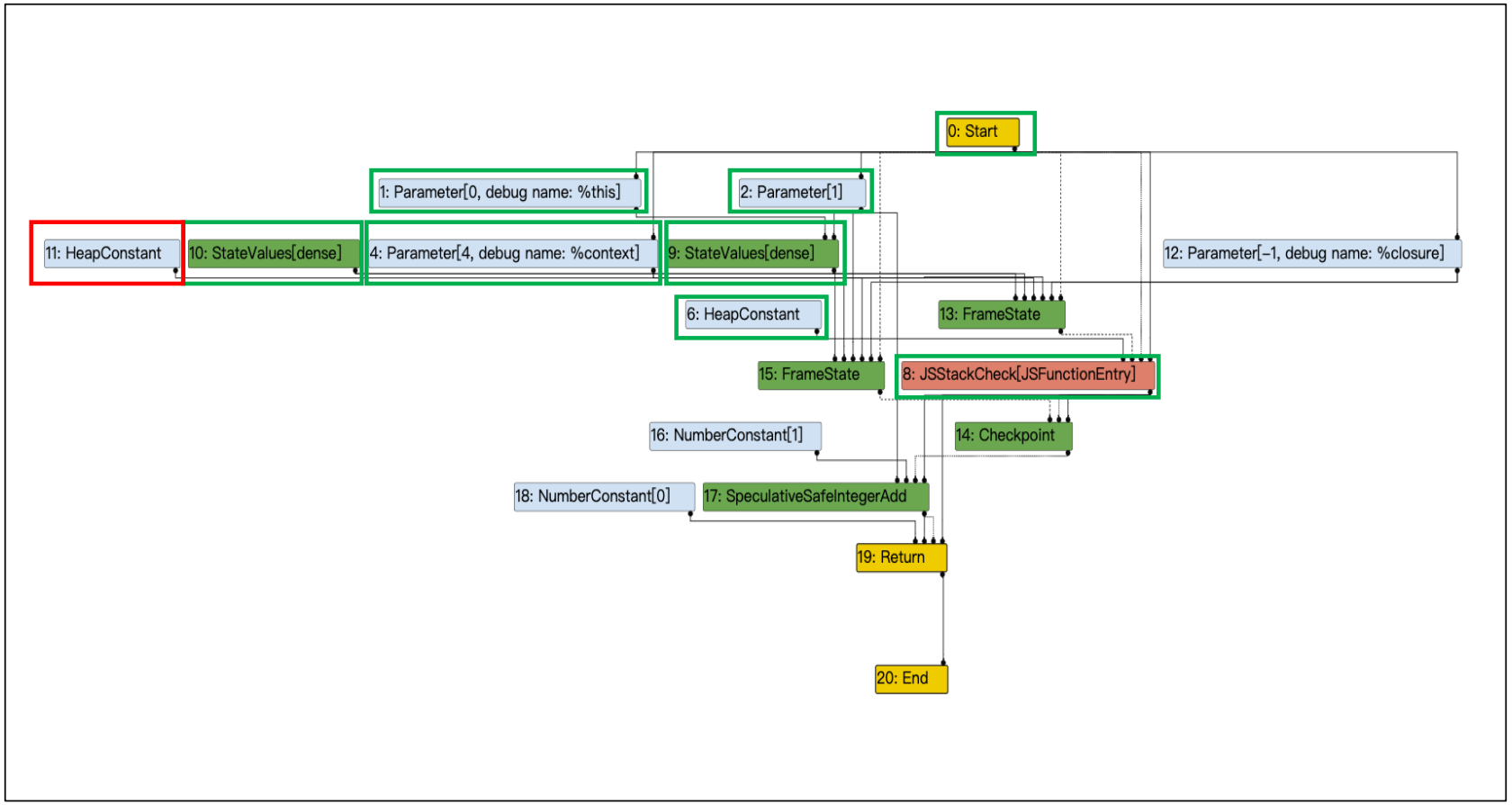
8	JSStackCheck	
9	StateValues	StateValues for parameter state, 作为FrameState的第一个输入
10	StateValues	StateValues for register states, 作为FrameState的第二个输入

Step7.6: accumulator_state_value

@src/compiler/bytecode-graph-builder.cc： BytecodeGraphBuilder::Environment::Checkpoint()

```
    bool accumulator_is_live = !liveness || liveness->AccumulatorIsLive();
    Node* accumulator_state_value = //FrameState的第三个输入：accumulator_state_value
      accumulator_is_live && combine != OutputFrameStateCombine::PokeAt(0)
          ? values()->at(accumulator_base())
          : builder()->jsgraph()->OptimizedOutConstant(); //在函数入口处，accumulator liveness是false，所以直接生成一个HeapConstant节点作为accumulator的state
```

已构建完成的节点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10	StateValues	StateValues for register states, 作为FrameState的第二个输入
11	HeapConstant	StateValues for accumulator states,作为FrameState的第三个输入

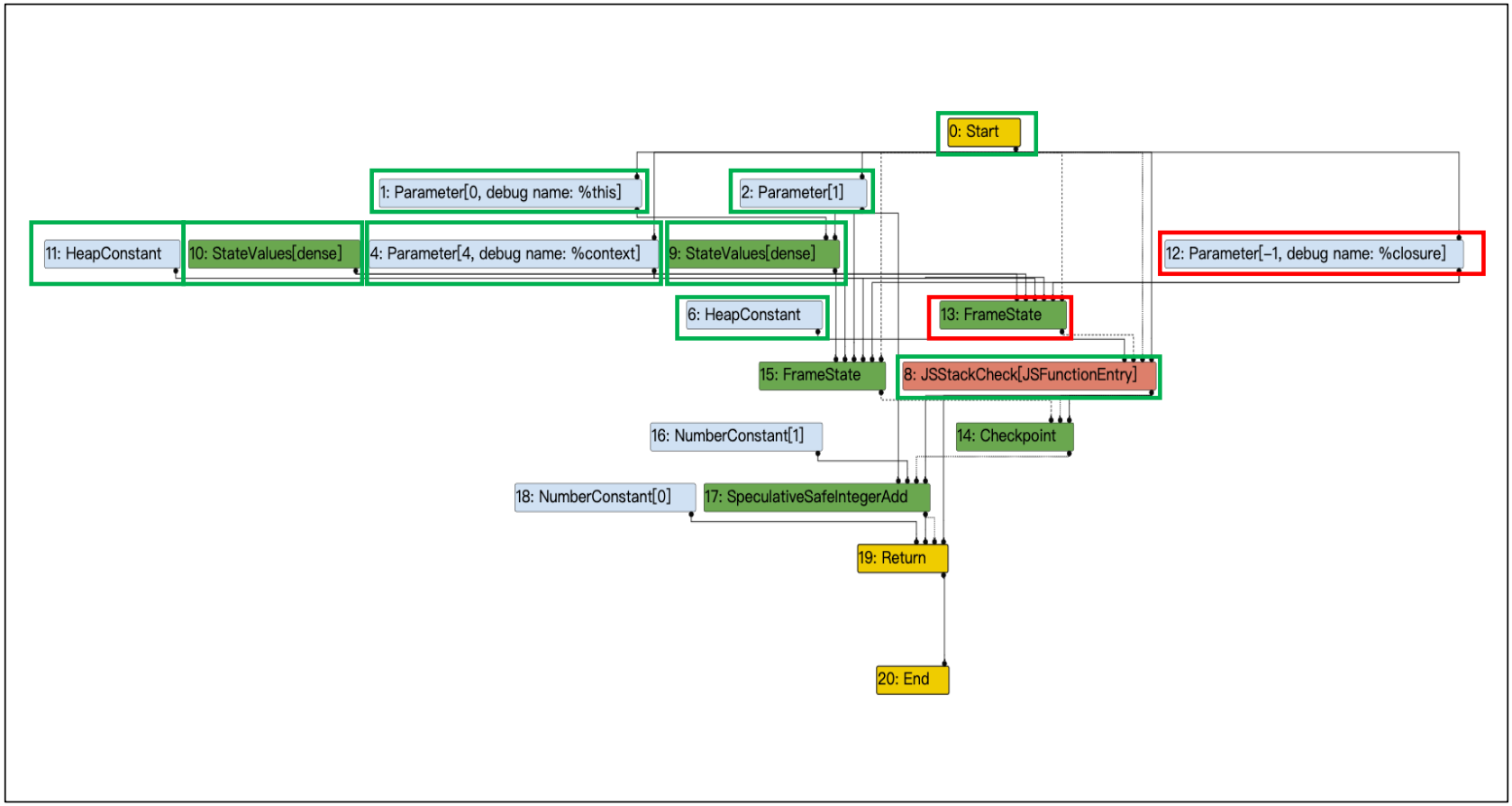
Step7.7: new FrameState node for StackCheck

@src/compiler/bytecode-graph-builder.cc： BytecodeGraphBuilder::Environment::Checkpoint()

```
const Operator* op = common()->FrameState(
    bailout_id, combine, builder()->frame_state_function_info());
Node* result = graph()->NewNode( //新建FrameState节点
    op, parameters_state_values_, registers_state_values,
    accumulator_state_value, Context(), builder()->GetFunctionClosure(), //新建FunctionClosure节点
    builder()->graph()->start());
return result;
```

```
Node* BytecodeGraphBuilder::GetFunctionClosure() {
  if (!function_closure_.is_set()) {
    int index = Linkage::kJSCallClosureParamIndex;
    Node* node = GetParameter(index, "%closure");
    function_closure_.set(node);
  }
  return function_closure_.get();
}
```

已构建完成的节点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12	Parameter	StateValues for function closure states,作为FrameState的第四个输入
13	FrameState	替换JSStackCheck的一个Dummy输入

Step7.8: VisitSingleBytecode-整体流程

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::VisitSingleBytecode() {
  tick_counter_->TickAndMaybeEnterSafepoint();
  int current_offset = bytecode_iterator().current_offset();
  UpdateSourcePosition(current_offset);
  ExitThenEnterExceptionHandlers(current_offset);
  DCHECK_GE(exception_handlers_.empty() ? current_offset
                                        : exception_handlers_.top().end_offset_,
            current_offset);
  SwitchToMergeEnvironment(current_offset);

  if (environment() != nullptr) {
    BuildLoopHeaderEnvironment(current_offset);

    switch (bytecode_iterator().current_bytecode()) { //switch-case构成分派，visitor模式
#define BYTECODE_CASE(name, ...)       \
  case interpreter::Bytecode::k##name: \
    Visit##name();                     \
    break;
      BYTECODE_LIST(BYTECODE_CASE)
#undef BYTECODE_CASE
    } } }
```

Step7.9: VisitLdar: Ldar a0（第一条字节码）

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::VisitLdar() {
  Node* value =
      environment()->LookupRegister(bytecode_iterator().GetRegisterOperand(0)); //在environment的values_数组中找到a0寄存器对应的node
  environment()->BindAccumulator(value); //将environment中的values_数组中accumulator对应的node指针指向value
}
```

Step7.10: VisitAddSmi： AddSmi [1], [0]（第二条字节码）

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::VisitAddSmi() {
  FeedbackSource feedback = CreateFeedbackSource(
      bytecode_iterator().GetSlotOperand(kBinaryOperationSmiHintIndex));
  BuildBinaryOpWithImmediate(javascript()->Add(feedback));
}
```

Step7.10: BuildBinaryOpWithImmediate

@src/compiler/bytecode-graph-builder.cc

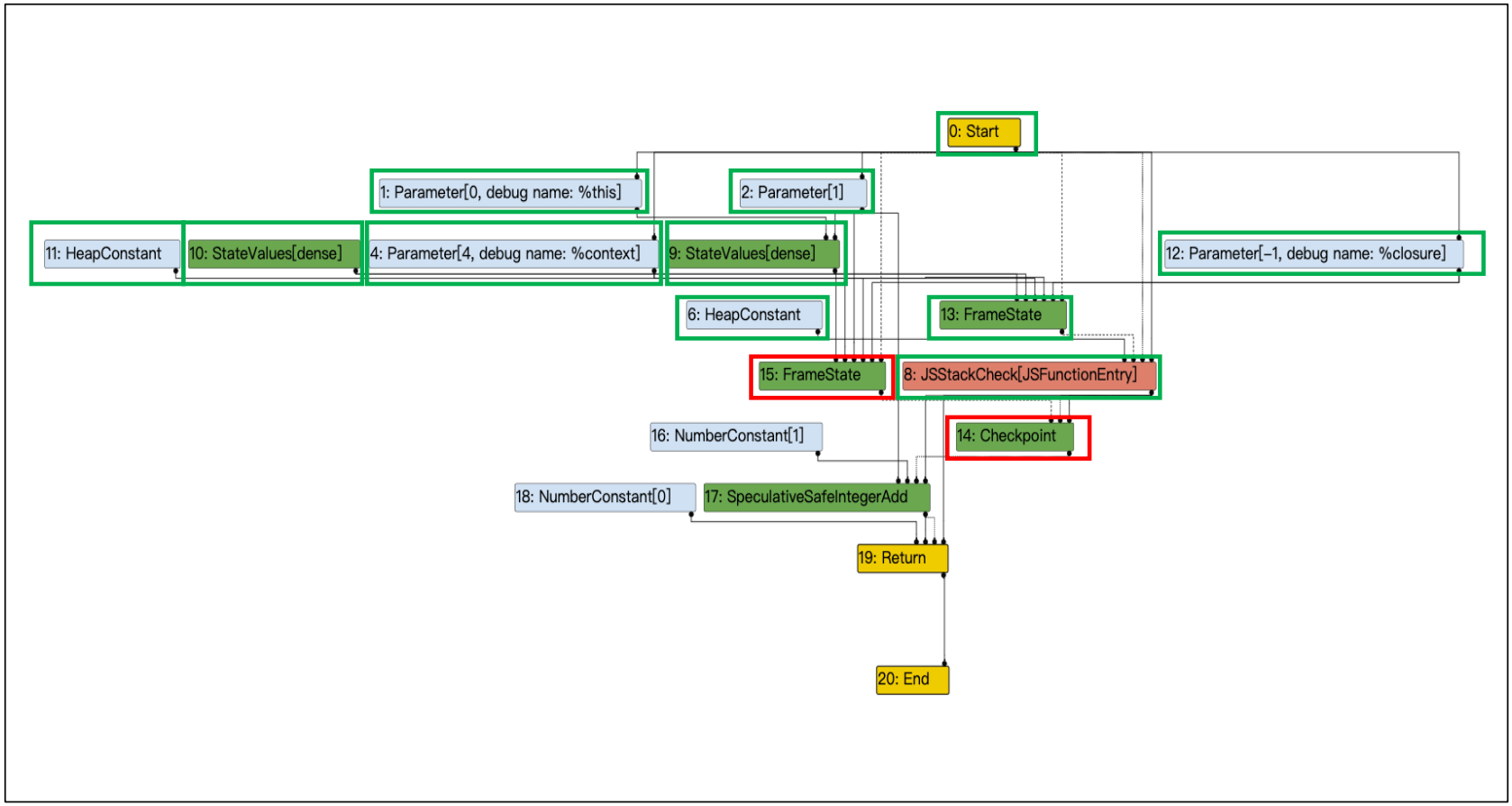
```
void BytecodeGraphBuilder::BuildBinaryOpWithImmediate(const Operator* op) {
  DCHECK(JSOperator::IsBinaryWithFeedback(op->opcode()));
  PrepareEagerCheckpoint(); //Step 7.11 准备生成激进的CheckPoint
  Node* left = environment()->LookupAccumulator(); //从env中找到accumulator对应的node节点
  Node* right = jsgraph()->Constant(bytecode_iterator().GetImmediateOperand(0)); //Step 7.12将右操作数的常量1，
生成一个constant节点
  FeedbackSlot slot =
      bytecode_iterator().GetSlotOperand(kBinaryOperationSmiHintIndex); //从[0]中获得slot
  JSTypeHintLowering::LoweringResult lowering =
      TryBuildSimplifiedBinaryOp(op, left, right, slot); //尝试构建SimplifiedBinaryOp
  if (lowering.IsExit()) return;
  Node* node = nullptr;
  if (lowering.IsSideEffectFree()) {
    node = lowering.value();
  } else {
    DCHECK(!lowering.Changed());
    DCHECK(IrOpcode::IsFeedbackCollectingOpcode(op->opcode()));
    node = NewNode(op, left, right, feedback_vector_node());
  }
  environment()->BindAccumulator(node, Environment::kAttachFrameState);
}
```

Step7.11: PrepareEagerCheckpoint

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::PrepareEagerCheckpoint() {
  if (needs_eager_checkpoint()) {
    // Create an explicit checkpoint node for before the operation. This only
    // needs to happen if we aren't effect-dominated by a {Checkpoint} already.
    mark_as_needing_eager_checkpoint(false);
    Node* node = NewNode(common()->Checkpoint()); //创建一个checkpoint节点，跟StackCheck类似，它也需要一个Dummy的Dead FrameState节点，但之前已经有Dead节点了，所以不需要再次创建
    BytecodeOffset bailout_id(bytecode_iterator().current_offset()); //得到addsmi指令位置对应的bailout id
    const BytecodeLivenessState* liveness_before =
        bytecode_analysis().GetInLivenessFor(bytecode_iterator().current_offset()); //得到addsmi指令前的register liveness
    Node* frame_state_before = environment()->Checkpoint(
        bailout_id, OutputFrameStateCombine::Ignore(), liveness_before);  //从environment中查找这条指令前的checkpoint对应的FrameState，步骤同前述7.3～7.7过程
    NodeProperties::ReplaceFrameStateInput(node, frame_state_before); //将CheckPoint的Dead FrameState替换成AddSmi对应的FrameState节点
}
```

已构建完成的节点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13	FrameState	替换JSStackCheck的一个Dummy输入
14	CheckPoint	作为AddSmi操作的Eager Checkpoint
15	FrameState	作为14号Checkpoint的FrameState输入

Step7.12: 为AddSmi的常量操作数1生成Constant节点

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::BuildBinaryOpWithImmediate(const Operator* op) {
  DCHECK(JSOperator::IsBinaryWithFeedback(op->opcode()));
  PrepareEagerCheckpoint();
  Node* left = environment()->LookupAccumulator();
  Node* right = jsgraph()->Constant(bytecode_iterator().GetImmediateOperand(0)); //Step 7.12将右操作数的常量1，
生成一个constant节点
  FeedbackSlot slot =
      bytecode_iterator().GetSlotOperand(kBinaryOperationSmiHintIndex); //从[0]中获得slot
  JSTypeHintLowering::LoweringResult lowering =
      TryBuildSimplifiedBinaryOp(op, left, right, slot);
  if (lowering.IsExit()) return;
  Node* node = nullptr;
  if (lowering.IsSideEffectFree()) {
    node = lowering.value();
  } else {
    DCHECK(!lowering.Changed());
    DCHECK(IrOpcode::IsFeedbackCollectingOpcode(op->opcode()));
    node = NewNode(op, left, right, feedback_vector_node());
  }
  environment()->BindAccumulator(node, Environment::kAttachFrameState);
}
```

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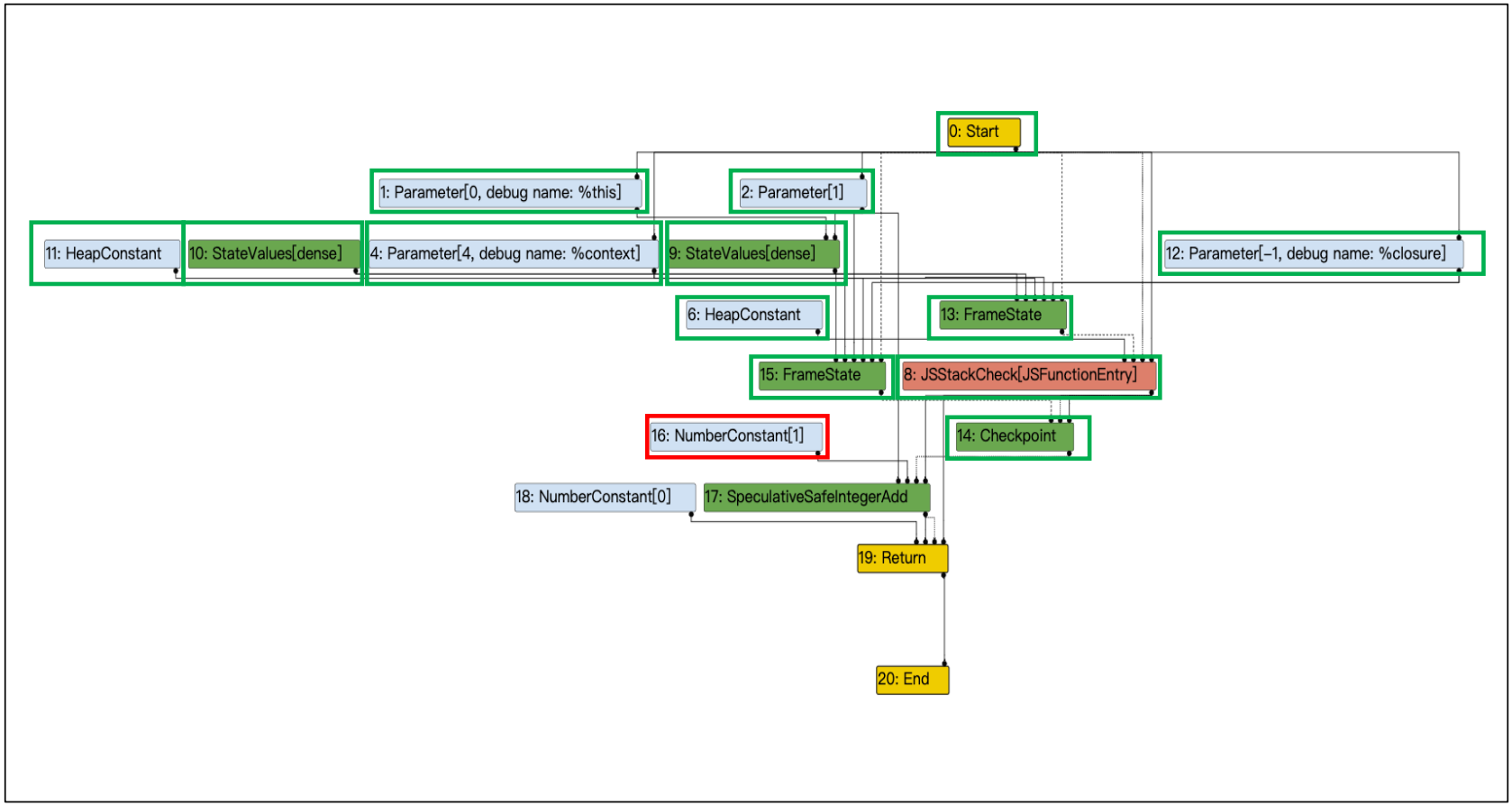
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14	CheckPoint	作为AddSmi操作的Eager Checkpoint
15	FrameState	作为14号Checkpoint的FrameState输入
16	NumberConstant	AddSmi的常量操作数1

Step7.13: TrySimplifiedBinaryOp

@src/compiler/bytecode-graph-builder.cc

```
JSTypeHintLowering::LoweringResult
BytecodeGraphBuilder::TryBuildSimplifiedBinaryOp(const Operator* op, Node* left,
                                                 Node* right,
                                                 FeedbackSlot slot) {
  Node* effect = environment()->GetEffectDependency();
  Node* control = environment()->GetControlDependency();
  JSTypeHintLowering::LoweringResult result =
      type_hint_lowering().ReduceBinaryOperation(op, left, right, effect, control, slot); //Step7.14
ReduceBinaryOperation
  ApplyEarlyReduction(result); //更新environment的control和effect依赖状态
  return result;
}
```

- type_hint_lowing()函数返回JSTypeHintLowing类型的成员对象type_hint_lowering
- JSTypeHintLowing类用于在从Bytecode构建SON图的过程中，根据FeedbackSlot提供的类型反馈信息，直接创建speculative simplified operator（跳过了本来应该创建的较高语义层次的JS operator）

Step7.14: ReduceBinaryOperation

@src/compiler/js-type-hint-lowering.cc

```
JSTypeHintLowering::LoweringResult JSTypeHintLowering::ReduceBinaryOperation(
    const Operator* op, Node* left, Node* right, Node* effect, Node* control, FeedbackSlot slot) const {
  switch (op->opcode()) {
  ...many ops...
    case IrOpcode::kJSAdd: {
      if (Node* node = TryBuildSoftDeopt(
              slot, effect, control, DeoptimizeReason::kInsufficientTypeFeedbackForBinaryOperation)) {
        return LoweringResult::Exit(node); } // SoftDeopt意味着FB信息还不足够，需要SoftDeopt到解释器
      JSSpeculativeBinopBuilder b(this, op, left, right, effect, control, slot); //创建JSSpeculativeBinopBuilder对象
      if (Node* node = b.TryBuildNumberBinop()) { //Step 7.15 执行TryBuildNumberBinop
            return LoweringResult::SideEffectFree(node, node, control); // 如果可以正确地BuildNumberBinop，那么，这
样的计算节点是不会引起Deopt的，没有副作用，所有返回SideEffectFree类型的LoweringResult
      }
      if (op->opcode() == IrOpcode::kJSAdd || op->opcode() == IrOpcode::kJSSubtract) {
        if (Node* node = b.TryBuildBigIntBinop()) { //如果反馈信息不是SmallInt，则尝试BuildBigIntBinop
          return LoweringResult::SideEffectFree(node, node, control);
        }}
      break; }
```

Step7.15: TryBuildNumberBinop

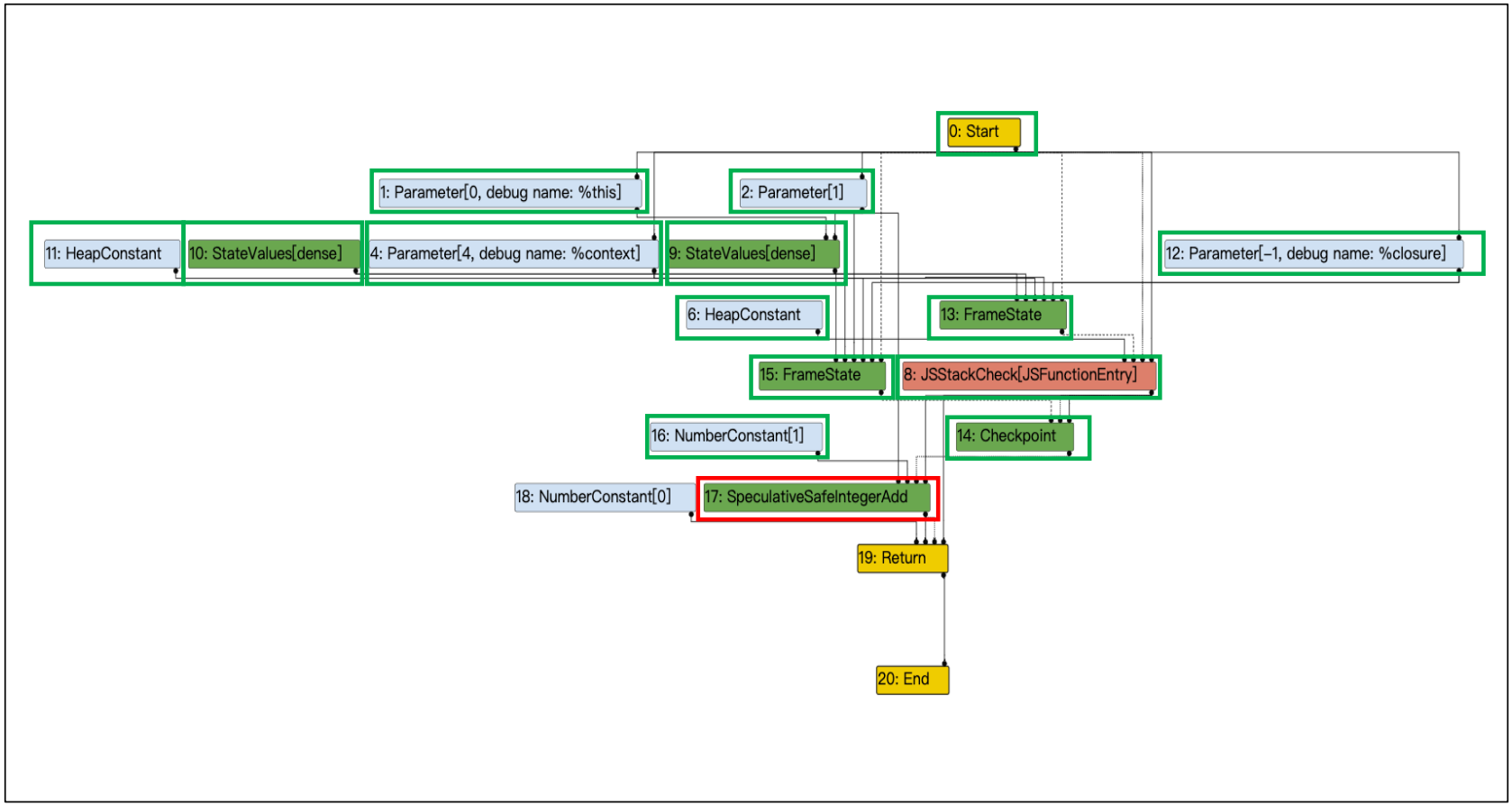
@src/compiler/js-type-hint-lowering.cc:

```
Node* TryBuildNumberBinop() {
    NumberOperationHint hint;
    if (GetBinaryNumberOperationHint(&hint)) { //从fb slot中得到type的hint判断它是不是BinaryNumber
      const Operator* op = SpeculativeNumberOp(hint); //得到SpeculativeSafeIntegerAdd opcode
      Node* node = BuildSpeculativeOperation(op); //最后调用得到SpeculativeSafeIntegerAdd的节点
      return node;
    }
    return nullptr;
  }
```

@src/compiler/js-type-hint-lowering.cc:

```
Node* BuildSpeculativeOperation(const Operator* op) {
    return graph()->NewNode(op, left_, right_, effect_, control_); //创建SpeculativeSafeIntegerAdd节点
  }
```

已构建完成的节点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10: StateValues[dense]
4: Parameter[4, debug name: %context]
9: StateValues[dense]
12: Parameter[-1, debug name: %closure]
6: HeapConstant
13: FrameState
15: FrameState
8: JSStackCheck[JSFunctionEntry]
16: NumberConstant[1]
14: Checkpoint
18: NumberConstant[0]
17: SpeculativeSafeIntegerAdd
19: Return
20: End

节点列表

0	Start	
1	Parameter	*this
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8	JSStackCheck	
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14	CheckPoint	作为AddSmi操作的Eager Checkpoint
15	FrameState	作为14号Checkpoint的FrameState输入
16	NumberConstant	AddSmi的常量操作数1
17	SpeculativeSafeIntegerAdd	加法的节点

Step7.16: Build Add操作扫尾：判断type_hint_lowering结果的属性

```
void BytecodeGraphBuilder::BuildBinaryOpWithImmediate(const Operator* op) {
  DCHECK(JSOperator::IsBinaryWithFeedback(op->opcode()));
  PrepareEagerCheckpoint(); //Step 7.11 准备生成激进的CheckPoint
  Node* left = environment()->LookupAccumulator(); //从env中找到accumulator对应的node节点
  Node* right = jsgraph()->Constant(bytecode_iterator().GetImmediateOperand(0)); //Step 7.12将右操作数的常量1，
生成一个constant节点
  FeedbackSlot slot =
      bytecode_iterator().GetSlotOperand(kBinaryOperationSmiHintIndex); //从[0]中获得slot
  JSTypeHintLowering::LoweringResult lowering =
      TryBuildSimplifiedBinaryOp(op, left, right, slot); //尝试构建SimplifiedBinaryOp
  if (lowering.IsExit()) return; // 返回的LoweringResult，如果Lowering的成Deopt节点了，就会导致退出JITed code，IsExit
就为true
  Node* node = nullptr;
  if (lowering.IsSideEffectFree()) {
    node = lowering.value(); //如果生成了Speculative的操作，那么SideEffect就是Free的
  } else {
    DCHECK(!lowering.Changed());
    DCHECK(IrOpcode::IsFeedbackCollectingOpcode(op->opcode()));
    node = NewNode(op, left, right, feedback_vector_node());
  }
  environment()->BindAccumulator(node, Environment::kAttachFrameState); //将node，也就是加法操作的结果绑定到
enviornment上去
}
```

*side effect free 是指不对图的其他部分产生额外的控制流和内存读写顺序的约束

Step7.17: Build Add操作扫尾：ApplyEarlyReduction

```
JSTypeHintLowering::LoweringResult
BytecodeGraphBuilder::TryBuildSimplifiedBinaryOp(const Operator* op, Node* left,
                                                 Node* right,
                                                 FeedbackSlot slot) {
  Node* effect = environment()->GetEffectDependency();
  Node* control = environment()->GetControlDependency();
  JSTypeHintLowering::LoweringResult result =
      type_hint_lowering().ReduceBinaryOperation(op, left, right, effect, control, slot); //Step7.14
ReduceBinaryOperation
  ApplyEarlyReduction(result); //Step 7.17 更新environment的control和effect依赖状态
  return result;
}
```

```
void BytecodeGraphBuilder::ApplyEarlyReduction(JSTypeHintLowering::LoweringResult reduction) {
  if (reduction.IsExit()) { MergeControlToLeaveFunction(reduction.control()); }
  else if (reduction.IsSideEffectFree()) {
    environment()->UpdateEffectDependency(reduction.effect()); //更新env的effect
    environment()->UpdateControlDependency(reduction.control()); //更新env的control
  } else {
    DCHECK(!reduction.Changed());
  }
}
```

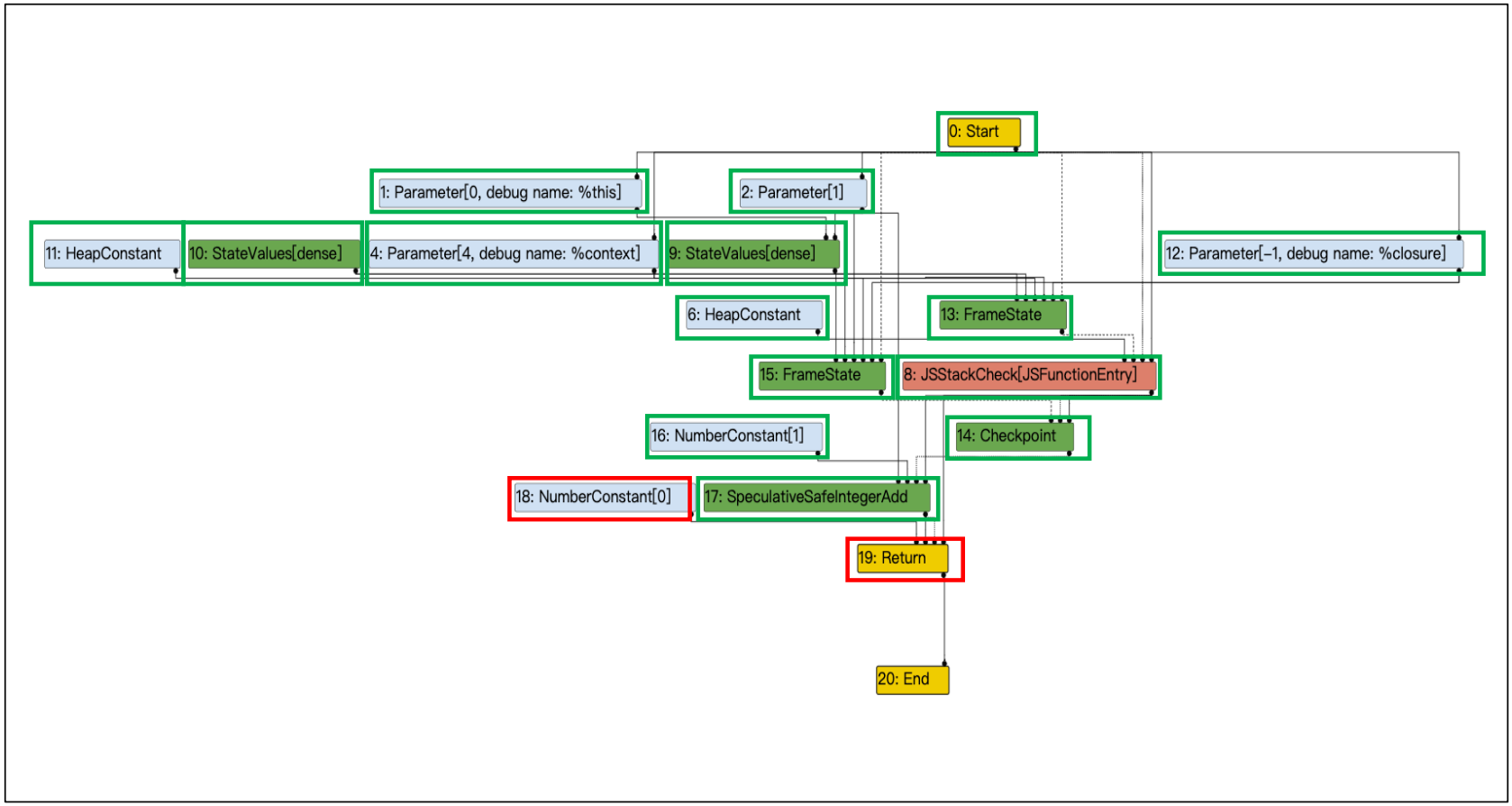
Step7.18: VisitReturn： Return（第三条字节码）

```
void BytecodeGraphBuilder::VisitReturn() {
  BuildReturn(bytecode_analysis().GetInLivenessFor(bytecode_iterator().current_offset()));
}

void BytecodeGraphBuilder::BuildReturn(const BytecodeLivenessState* liveness) {
  BuildLoopExitsForFunctionExit(liveness);
  // Note: Negated offset since a return acts like a backwards jump, and should
  // decrement the budget.
  BuildUpdateInterruptBudget(-bytecode_iterator().current_offset()); //还记得在解释器中介绍过的用于TierUp进入时机判断的InterruptBudget么？它被初始化成一个大于0的量，在字节码执行过程中，遇到向后跳转或者顺序执行就减少，遇到向前跳转就增加，减成0之后就开始判断是否可以TierUP JIT。如果当前的JIT过程嗨可以TierUP，就这里把整个test函数的字节码size从Budget中减去
  Node* pop_node = jsgraph()->ZeroConstant(); //创建返回值0的常量节点
  Node* control =
      NewNode(common()->Return(), pop_node, environment()->LookupAccumulator()); //创建return节点
  MergeControlToLeaveFunction(control); //exit control的merge
}

void BytecodeGraphBuilder::MergeControlToLeaveFunction(Node* exit) {
  exit_controls_.push_back(exit); //将return节点加入SON图的exit_controls_, SON图的exit节点必须受控于该return节点
  set_environment(nullptr); //env置成null
}
```

已构建完成的节点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17	SpeculativeSafeIntegerAdd	加法的节点
18	HeapConstant	返回值0
19	SpeculativeSafeIntegerAdd	加法操作

Step by Step, Node by Node讲述图的构建过程

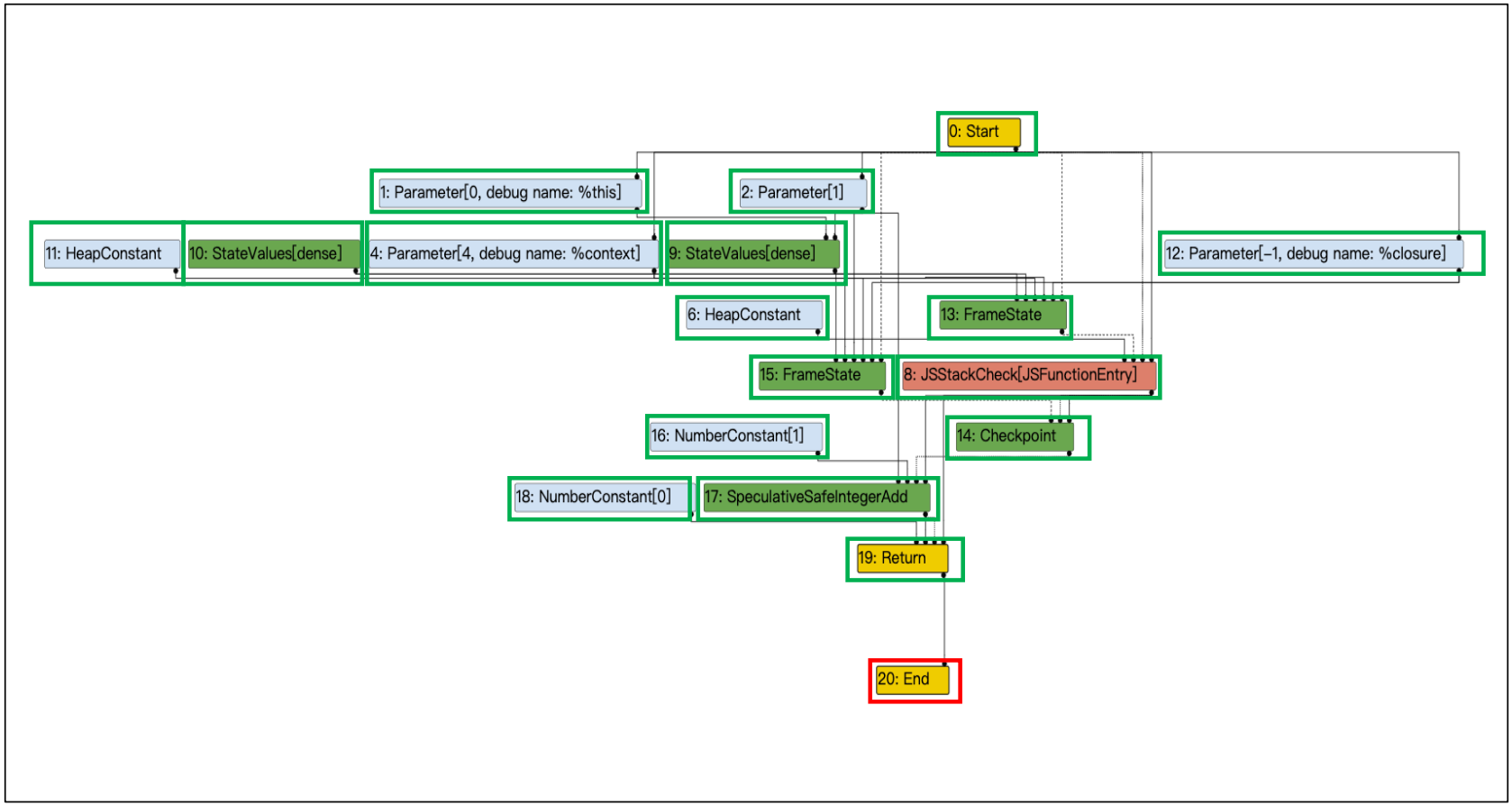
1. new and set the Start node
2. new Environment and set_environment
3. CreateFeedbackCellNode
4. CreateFeedbackVectorNode
5. MaybeBuildTierUpCheck
6. CreateNativeContextNode
7. VisitBytecodes: one by one
8. new and set the End node

Step 8: new and set the End node

@src/compiler/bytecode-graph-builder.cc

```
void BytecodeGraphBuilder::CreateGraph() {
  … …
    // Finish the basic structure of the graph.
  DCHECK_NE(0u, exit_controls_.size());
  int const input_count = static_cast<int>(exit_controls_.size());
  Node** const inputs = &exit_controls_.front();
  Node* end = graph()->NewNode(common()->End(input_count), input_count, inputs); //创建End节点，End节点的输入是该图所有的exit_control节点
  graph()->SetEnd(end); //set End node
}
```

已构建完成的节点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20	End	

从Bytecode到SON图的构建：总结

- Demo case 及其 Graph
- 总体构建流程概述
- Step by Step, Node by Node讲述图的构建过程
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  2. new Environment and set_environment
  3. CreateFeedbackCellNode
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  7. VisitBytecodes: one by one
  8. new and set the End node

- 了解了一个简单的case的“复杂地”SON图构建流程
- 了解了SON图的结构和构建的相关函数
- 为后续讲解TurboFan的SON图变换和优化打下基础

谢 谢

欢迎交流合作